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STATUS OF INDUSTRY PROGRESS TOWARDS ACHIEVEMENT OF THE 1975 FEDERAL EMISSION STANDARDS FOR LIGHT-DUTY VEHICLES

W. V. Roessler, et al

Aerospace Corporation

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A compilation of the data available which showed the progress made as of mid 1972 by the Automobile Manufacturers toward meeting the 1975 model year emission standards. Each approach to meeting the standards is discussed and referenced to the manufacturers using that approach.

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by

W. U. Roessler, T. Iura, and J. Meltzer

Aerospace Corporation
El Segundo, California

Contract No. 68-01-0417

EPA Project Officer: F. Peter Hutchins

Prepared for

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Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

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FOREWORD

This report, prepared by The Aerospace Corporation for the Environmental Protection Agency, Division of Emission Control Technology, presents a compilation and assessment of all available information pertaining to the technological progress made by the automotive industry toward meeting the 1975 Federal emission standards for light-duty vehicles.

The status of the technology reported here is that existing at the time of the EPA Suspension Request Hearings held in Washington, D.C., between April 10 - 28, 1972. Important findings and conclusions are presented in the Highlights and Executive Summary sections of the report. Material related to candidate 1975 emission control systems is given in Section 2. An assessment of emission control techniques and system components (engine modifications, EGR (exhaust gas recirculation), oxidation catalysts, thermal reactors, and secondary air supply) is presented in Sections 3 through 7. Engineering emission goals and emission control system deterioration characteristics with mileage accumulation are discussed in Section 8. The interim standards proposed by the automobile manufacturers are summarized in Section 9 and maintenance, cost, safety and production lead time aspects are briefly discussed in Sections 10 and 11. Section 12 presents a brief status report of unconventional automotive engines, including the rotary (Wankel), diesel, gas turbine, stratified charge, Rankine cycle, and Stirling cycle. Finally, the highlights of the statements made at the EPA Suspension Request Hearings of April 10 - 28, 1972 by witnesses who are not a part of the automotive industry are presented in Appendix A.

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J. A. Drake
L. Forrest
M. G. Hinton
D. E. Lapedes
P. P. Leo
W. M. Smalley
C. Speisman
K. B. Swan

W. U. Roessler

W. U. Roessler, Manager
Technology Assessment Study

Approved by:

Toru Iura, Director
Pollution and Resources Programs

Joe Meltzer

Joseph Meltzer, Group Director
Environmental Programs Directorate

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HIGHLIGHTS

A review and evaluation was made of all available information pertinent to the technological progress of the automotive industry in meeting the 1975 Federal emission standards for light duty vehicles. Assessment of the status of the industry as of the time of the EPA Suspension Request Hearings (April 10-28, 1972) resulted in the following findings.

1. All but a small fraction of the 1975 model year light duty vehicle production will utilize spark ignition reciprocating engines. The typical 1975 first-choice emission control system is based on the use of an oxidizing catalytic converter. Additional features of the system include exhaust gas recirculation, improved carburetion and ignition, and devices or techniques to promote fast warmup of the induction system and catalytic converter.
2. In addition to spark ignition reciprocating engine systems, Toyo Kogyo will produce rotary engine vehicles and Daimler-Benz will produce diesel engine vehicles for the 1975 U.S. market. The Toyo Kogyo rotary engine emission control system consists only of the addition of a thermal reactor. The Daimler-Benz diesel vehicle (220D) is stated to be capable of meeting 1975 standards without aftertreatment devices.
3. The Toyo Kogyo rotary engine emission control system has successfully achieved the company's 1975 low mileage emission goals. Toyo Kogyo expressed optimism that its system would be able to meet the 1975 standards. However, this type of engine cannot be produced in sufficient quantities by the automotive industry to satisfv any significant fraction of the 1975 production requirements.
4. Daimler-Benz believes that a vehicle with a pre-chamber diesel engine of the 2.2-liter class can meet the 1975 standards without the use of aftertreatment devices. It is unlikely that this type of

engine can meet the 1976 NO_x standards. The current low production rate of this engine cannot be increased substantially by 1975.

5. Although the emission potentials of the stratified charge, the gas turbine, the Rankine, and the Stirling engines look promising and although substantial progress on them has been made in recent years, they are still in the development stage and a number of technical problem areas have yet to be resolved, including the development of mass production techniques. Therefore, mass production of these engines cannot be scheduled at this time.

6. No manufacturer has yet demonstrated meeting the 1975 standards at 50,000 miles. Many automobile and catalyst manufacturers have met the 1975 standards at low mileage.

7. Only a limited number of test vehicles have been driven in extended durability tests beyond 20,000 miles. Johnson-Matthey has tested a car equipped with a noble metal monolithic catalyst which had emission levels below the 1975 standards through the 24,000-mile test duration to date. However, lead-sterile fuel was used. American Motors, Chrysler, General Motors, and Volvo have longer mileage accumulations ranging from 25,000 to 50,000 miles. Although these tests were encouraging in that emission levels were below the standards at discrete mileage points, they must be viewed with caution since in all cases there were some factors present which preclude direct comparison of the emission data with the 1975 standards. These include high emissions at intermediate mileage points, non-standard driving cycles, obsolete test procedures, and/or use of fuel with a lead content below that anticipated for 1975.

8. The available emission data may reflect conservative emission levels becaus , in most cases, the vehicles tested did not include all of the emission control system components or improvements projected for the 1975 systems. Current fleet tests, which in many cases include prototypes of the proposed system components, should give an

indication of the degree of emission reduction attributable to these components.

9. Improved catalysts are being developed and tested by the catalyst industry and have shown better emission performance and durability characteristics. However, they have not yet been tested in conjunction with the proposed 1975 vehicle/emission control system configurations. Only after durability testing in 1975 prototype vehicles can a quantitative assessment be made of the emission control potential of these improved catalysts.

10. The manufacturers' low mileage emission goals for 1975 prototype emission control systems are substantially lower than the 1975 standards to allow for prototype-to-production design and performance variations and to allow for anticipated deterioration in emission control with mileage accumulation. With the exception of the Toyo Kogyo rotary engine these low mileage goals have not been met.

11. Test data from some vehicles equipped with catalytic converters indicate rapid emission degradation during the low mileage (0-4,000 miles) period followed by either gradual or no deterioration as mileage is accumulated. Other catalytic converter vehicle tests do not show the initial rapid deterioration and exhibit a gradual emission deterioration with mileage accumulation. Therefore, deterioration factors determined from one type of vehicle/emission control system are not necessarily applicable to other configurations. Available emission data suggest that emission degradation is more severe for systems with initially low emissions.

12. All manufacturers have requested adoption of interim standards less stringent than the 1975 standards. The proposed interim standards range from values equal to the 1974 standards to approximately 40 percent of these values. Even this 40 percent value is still substantially higher than the 1975 standards. Most automobile manufacturers have proposed interim standards that can be met by means

of engine modifications. Only Ford and International Harvester selected interim standards which require the use of a catalytic converter.

13. The catalytic converter is the most critical component in 1975 emission control systems because of the 50,000-mile durability requirement. Oxidation catalysts have inherent performance degradation and physical durability problems which to date have not been completely resolved. Loss of catalytic activity is caused by contamination from fuel and oil additives, such as lead, phosphorous, sulfur, barium, and zinc, and by loss of catalytic surface area caused by exposure to excessive temperature. The physical durability problems relate to thermal stresses, vibrational loads, and over-temperature conditions which have caused mechanical failure of the catalyst substrate and/or its container.

14. Although catalyst development is proceeding on both noble and base metal catalysts using monolithic or pellet substrates, most manufacturers are concentrating their efforts on noble metal/monolithic catalytic converters. To date the lowest emission data at high mileage were reported for a vehicle incorporating a noble metal/monolithic catalyst.

15. Although quantitative relationships between lead content and emissions have not yet been established it is the opinion of some automobile and catalyst manufacturers that catalyst performance is strongly affected by the lead content in fuel, even at lead levels below 0.07 gm/gal. If this effect is confirmed a maximum lead level should be established which takes into consideration both catalyst performance as well as fuel refinery and handling aspects at low lead levels.

16. With the exception of Toyo Kogyo, thermal reactor-only systems are not being considered by the automobile manufacturers as first-choice systems. Although the thermal reactor has low emission degradation and is relatively insensitive to fuel contamination, most automobile

manufacturers have reported such negative aspects as poor mechanical durability, high underhood temperatures, and low fuel economy. In addition, 1976 NO_x standards cannot be met with the thermal reactor alone.

17. The catalytic converter is the pacing production development item that impacts on the production lead time requirement for the mass production of 1975 emission control systems. Based on information from both the automobile manufacturers and catalyst suppliers, the overall lead time for catalytic converter production ranges from 24 to 28 months (this requires a firm commitment in mid-1972). Some catalyst suppliers have estimated that further schedule compressions can be made, but with corresponding increases in unit costs. Sufficient information was not available to allow a critical evaluation of schedule compression possibilities and effects.

18. Several important issues which have a great effect on whether the automobile manufacturers can meet the 1975 standards are still unresolved. These include emission averaging for certification and assembly line vehicles, maximum allowable fuel contaminant levels, clarification of maintenance procedures for all emission control system components, and definition of warranty and recall procedures. All these issues must be resolved before a quantitative evaluation of the manufacturers' ability to comply can be made.

19. A number of automobile manufacturers have expressed the opinion that the applicability of the EPA certification driving cycle to vehicles incorporating a catalytic converter and/or thermal reactor should be re-examined. The cycle may be too mild to adequately test the emission performance and safety aspects of these systems.

EXECUTIVE SUMMARY

1. INTRODUCTION

This report presents a compilation and assessment of all available information pertaining to the technological progress made by the automotive industry toward meeting the 1975 Federal emission standards for light duty vehicles (HC = 0.41 gm/mi, CO = 3.40 gm/mi, NO_x = 3.10 gm/mi).

The status of technology reported here is that existing at the time of the EPA Suspension Request Hearings held in the period of April 10-28, 1972. Information was taken from material in the manufacturers' applications for suspension of the 1975 emission standards, testimony presented at the hearings, and supplementary material provided by the hearing witnesses at the request of the hearing panel. To supplement this information in certain areas, data were used from previous responses by industry to EPA requests for technology information.

Topics covered in this report include first-choice emission control systems, possible alternate systems, unconventional engine designs, and emission control system components. Emphasis has been directed toward low and high mileage emissions, component and system durability characteristics (in particular, catalytic converters), and factors affecting emission goals and interim standards.

This section of the report summarizes the more pertinent information from this assessment. Further details can be found in the main body of the report.

2. CANDIDATE 1975 EMISSION CONTROL SYSTEMS

The emission control systems projected for 1975 model vehicles are exemplified by the following package of components and engine modifications:

Oxidizing catalytic converter
Air injection

Exhaust gas recirculation (EGR)
Carburetor modifications
Ignition system modifications

With the exception of Toyo Kogyo, which utilizes a thermal reactor on their rotary engine, all of the manufacturers' first-choice systems incorporate an oxidizing catalytic converter with air injection to promote the oxidation of unburned hydrocarbons (HC) and carbon monoxide (CO) of the engine exhaust. The catalytic converter type which appears most frequently among the selected first-choice systems is the noble metal/monolithic catalyst exemplified by the Engelhard PTX design. General Motors, International Harvester, and a number of other manufacturers have selected the base metal/pelletized type of converter as a first-choice design. In many cases, a firm decision as to catalyst type has not been made and several systems are being tested and evaluated concurrently.

Nearly all of the first-choice systems employ EGR for the control of oxides of nitrogen (NO_x). However, most British Leyland and the Toyo Kogyo and Saab vehicles exported to the United States are reported to be capable of meeting the 1975 3.10 gm/mi NO_x standard without EGR.

In addition to the aftertreatment systems delineated above, a number of manufacturers, including Chrysler, General Motors, and Ford, utilize a partial thermal reactor in place of the conventional exhaust manifold, primarily to provide rapid warmup of the catalytic converter under cold start conditions.

Carburetion system modifications that have been identified for first-choice systems range from complete redesigns, utilizing new concepts, to minor improvements to the current conventional systems. These modifications are generally directed toward improving the precision and stability of the air/fuel ratio and also include such features as altitude compensation, quick release choke devices, and induction manifold heating. All of the domestic and several of the foreign manufacturers propose, or have in development, electronic (breakerless) ignition systems which are targeted for inclusion in their first-choice system. These systems generally provide an improvement in spark-timing precision, consistency, and reliability.

The most pervasive problem in the industry relative to 1975 emission control systems appears to be the lack of adequate durability in the catalytic converters currently under test. Catalyst durability is composed of two aspects: physical durability and emission durability. For monolithic designs, the physical aspect of the problem is symptomized by cracking and local melting of the catalyst substrate, due to vibratory loads and overtemperature. For pellet-type systems, the problem is exhibited as a loss of catalyst material caused by brittleness of the pellets and/or deficiencies in the design and construction of the support grids. Physical breakdown appears to be particularly severe in 4-cylinder engine systems because of characteristically high vibrations. Canister deformation and rupture failures have occurred with both types of converter designs.

The emission durability is most strongly impacted by a loss of catalyst efficiency with accumulated mileage without mechanical deterioration. The problem has several causes, including poisoning of the catalyst due to small quantities of lead, sulfur, or phosphorus in the fuel and/or loss of catalyst surface area due to overheating. The overheating effect appears to be primarily related to rich air/fuel operation and may be encountered under various engine/vehicle operating conditions including acceleration, deceleration, choking, high power operation, and malfunctions of different types.

In addition to the catalytic converter, durability problems with other 1975 emission system components are reported. Notable among these are EGR valves and thermal reactors.

Other problems which appear to be characteristic of the 1975 emission control systems are degradation of vehicle driveability, loss of vehicle performance, and deterioration of fuel economy. Driveability problems reported encompass the following: loss of cold start drive-away capability, stumbles, stalls, inadequate acceleration, difficulty in hot starting, rough idle, surging, hesitation, and backfire. Power losses and losses in fuel economy (relative to 1972 vehicles) range from 10 to 20 percent for both parameters.

With regard to the degradation of vehicle driveability, performance, and fuel economy, improvements are being sought by modifying the design of the fuel metering, induction, and ignition systems. Electronic engine control, which integrates the adjustment of ignition timing, air/fuel ratio, and EGR flow rate with respect to engine load and RPM, may provide the means to achieve an optimized balance between exhaust emissions versus vehicle performance and economy. Electronic engine control is a feature of the Chrysler first-choice system.

The emission performance of the 1975 systems is categorized in terms of low and high (4000^+) mileage accumulation. Many of the manufacturers' low mileage test results fall well within the 1975 standards; most of these systems drift outside the limits of the standards at low levels of mileage accumulation. In general, zero mileage vehicles do not meet the manufacturers' engineering emission goals.

The status of high mileage emission level capabilities for 1975 first-choice systems may be gauged from the summary of best high mileage emission results presented in Table 1. The emissions obtained at 32,000 miles from an American Motors Javelin (3000-lb, 6-cylinder, 258-CID engine) equipped with an AC-Delco base metal, pelletized catalytic converter (Car D17-11) were below the standards. However, the HC emission level at 32,000 miles is above the standard when determined on the basis of a straight-line, least-squares fit of all data points. This system is continuing to accumulate mileage (EPA durability driving schedule).

Two other high mileage vehicles may be noted. One of these is an American Motors 1970 production model Hornet (same vehicle weight and engine as the Javelin). This vehicle (Car D00-24), equipped with an Engelhard PTX 423 noble metal monolithic catalytic converter, has completed 50,000 miles of durability testing and at this mileage a least-squares data fit indicates

Table 1. First-Choice Systems, Summary of Best High Mileage Emission Results

Manufacturer	Test or Car No.	First-Choice System Components	Mileage	1975 CVS-CH Emissions, gm/mi HC	CO	NO_x	Remarks
American Motors	D17-11	EM + EGR + AI + OC	32,000	0.39	3.04	1.5	9, 12, Base OC
American Motors	D00-24	EM + EGR + AI + OC	50,000	(0.32	4.8	2.1)[1]	Noble OC
Chrysler	698	EM + EGR + AI + PTR + OC	43,000	(0.16	1.88	3.91)[2]	5, 8, 12, Noble OC
Ford	Ford #1	EM + EGR + AI (+ TR) + OC	8,000	0.25	1.84	2.55	9, 13, Noble OC
General Motors	2222	EM + EGR + AI + PTR + OC	8,000	0.32	4.6	2.6	9, Base OC
International Harvester	–	EM + EGR + AI + OC	4,000	0.33	4.7	–	3
Alfa Romeo	–	Not defined	–	–	–	–	6
BMW	–	EM + EGR + AI + OC	–	–	–	–	6
British Leyland	Austin	EM + AI + OC	11,400	0.28	2.73	2.32	7, Noble OC
Citroen	–	Not defined	–	–	–	–	6
Daimler-Benz	–	EM + EGR + AI + OC	–	–	–	–	6
Honda	–	Not defined	–	–	–	–	6
Mitsubishi	–	EM + AI (+ TR) + OC	10,000	0.5	3.9	–	3
Nissan	–	EM + EGR + AI + OC	8,000	0.2	1.2	0.78	14, Noble OC
Renault	R16	AI + OC	16,000	0.32	3.91	1.69	4, 10, Noble OC
Saab	–	EM + AI + OC	–	–	–	–	6, Noble OC
Toyo Kogyo	–	(EM) + AI + TR (+ OC for reciprocating)	–	–	–	–	6
Toyota	75-A	EM + EGR + AI + OC	8,000	0.27	2.82	1.29	5, 11, 14, Noble OC
Volkswagen	–	EM (+ EFI) + EGR + AI + TR + OC	–	–	–	–	6, Noble OC
Volvo	OB44085	EM + EGR + AI + OC	25,344[8]	0.24	2.45	1.82	5, 12, Noble OC

1. Least-squares fit to 1972 test results converted to 1975 test procedure; slow choke
2. 1972 CVS-C test procedure
3. No high mileage data met standards
4. Emissions package incomplete/uncertain
5. Converter subsequently failed (within 4000 miles)
6. No high mileage data provided
7. Exceeded standards below 17,000 miles
8. Converter miles
9. Test continuing
10. Average of two tests
11. After maintenance
12. Standards were exceeded at lower mileage points
13. Best of two tests
14. Non-standard maintenance schedule

AI – Air Injection
EFI – Electronic Fuel Injection
EGR – Exhaust Gas Recirculation
EM – Engine Modifications
OC – Oxidizing Catalyst
PTR – Partial Thermal Reactor
TR – Thermal Reactor

the emissions were 0.32, 4.8, and 2.1 gm/mi for HC, CO, and NO_x, respectively. The 1975 CO standard of 3.4 gm/mi was exceeded at roughly 30,000 miles. The other high mileage vehicle which is noteworthy is a 400-CID Chrysler car. This vehicle (Car 698), equipped with dual Engelhard platinum/monolith converters which had been transferred from another vehicle, developed a total converter mileage of 43,000 miles at emission levels of 0.16, 1.88, and 3.91 gm/mi for HC, CO, and NO_x, respectively. The catalyst container failed mechanically at this point.

In addition to the two high mileage vehicles discussed above, the Volvo first-choice emission vehicle might also be mentioned. This system accumulated 25,344 converter miles within standards. The catalyst failed mechanically at 29,900 miles.

Though not included in Table 1, because no high mileage emission data were provided, the Toyo Kogyo rotary engine with thermal reactor deserves special mention. Toyo Kogyo states that this system has met its internal engineering goals and is confident that it will achieve the 50,000-mile emissions durability requirement.

Summarizing the emissions performance indicated by the data in Table 1, eight first-choice systems have met the standards at accumulated mileages in excess of 4000 miles. None of these has achieved the 50,000-mile durability requirement; one system has met the standards at 32,000 miles and is still under test. A total of three systems have demonstrated the potential of achieving 25,000 converter miles within standards; two of the converters subsequently failed in test. A total of three catalytic converter failures occurred among the eight test vehicles which met the standards at more than 4000 miles.

In the main, the alternate systems under investigation by the manufacturers for potential use in 1975 model year vehicles incorporate different types or designs of catalytic converters but are otherwise similar to the emission control packages selected as first-choice systems. A typical example is General Motors, whose second- and third-choice systems substitute noble metal pellet and noble metal monolithic converter designs for the first-choice base metal pellet converter design. Therefore, the discussion in the preceding paragraphs, encompassing system descriptions, problems and plans for resolution, and fuel consumption and performance penalties, applies also to most of the systems in the alternate systems category.

At least four manufacturers are experimenting with alternate 1975 emission control systems which incorporate full-size thermal reactors. These are Ford, General Motors, International Harvester, and Nissan.* The Ford system is installed on their Group II test fleet vehicles which are equipped with dual (series) noble metal catalytic converters, a thermal reactor, and EGR. The General Motors system consists of a thermal reactor with EGR. Durability data for these systems were not provided. The International Harvester system exceeds the standards at zero mileage.

The Nissan system comprises engine modifications, a thermal reactor, EGR, and an oxidizing catalytic converter. Problems encountered with the Nissan reactor may be represented as being typical of thermal reactors. These problems are reactor core deformation and durability, and the need to develop inexpensive materials which will survive the high temperature, turbulent core environment. The fuel consumption penalty for the Nissan system was quoted as 10 to 15 percent relative to 1972 model year vehicles. The maximum mileage accumulated on this system was 32,000 miles at emission levels ranging from 0.5 to 0.75 gm/mi HC, 11 to 13 gm/mi CO, and 0.75 to 1.1 gm/mi NO_x. This system may be under development for 1976.

It may be noted that Toyota is testing a thermal reactor system which also appears to be targeted to the 1976 model year. This system incorporates engine modifications, EGR, an oxidizing catalyst, and a reducing catalyst. Two vehicles equipped with this system failed the CO standard before 8000 miles were accumulated.

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*The Toyo Kogyo thermal reactors are classified as first-choice devices.

3. UNCONVENTIONAL AUTOMOTIVE ENGINES

Automotive engine candidates classified here as unconventional include the Wankel, the stratified charge, the diesel, the gas turbine, and the Rankine and Stirling engine systems. The continuous combustion engine types (gas turbine, Rankine, Stirling) generally show encouraging emission results. However, the Rankine system is regarded by the automobile manufacturers as being too complex and costly for widespread automotive application and all three of these engine types are considered to be unavailable in sizeable production quantities before the 1980^+ time period. The light duty diesel engine, on the basis of anticipated test procedures and current test results, can meet the 1975 standards without exhaust treatment devices; however, the 1976 NO_x requirement appears to be unattainable by the diesel even when incorporating the techniques (e.g., EGR, NO_x catalyst) presently under consideration for internal combustion gasoline engines.

The Wankel rotary engine is being produced by Toyo Kogyo at a low production rate of about 15,000 per month for the Mazda vehicle and is also under study and development by Ford, General Motors, and Daimler-Benz. The untreated exhaust contains somewhat more HC, approximately the same CO, and considerably less NO_x than the conventional reciprocating engine. In general, the domestic manufacturers visualize the possible advantages of the Wankel to be primarily in the areas of reduced size and weight, which could permit the utilization of some emission control systems not suited to the conventional engine (e.g., large thermal reactor). Toyo Kogyo is confident that its rotary engine system equipped with a thermal reactor will demonstrate the capability of meeting the 50,000-mile emissions durability requirement. Nevertheless, the prospects of developing this engine for high-volume industry-wide production output in time for the 1975 or 1976 model year seem remote.

Another system offering the potential of low emissions is the stratified charge engine which achieves satisfactory (no misfire) operation at high EGR rates by providing a localized rich charge in the vicinity of the spark electrodes. This engine type, which incorporates a thermal reactor, EGR, and oxidizing catalyst, may permit the achievement of very low NO_x emissions without a NO_x catalyst and with relatively good fuel economy. The development of the stratified charge engine is being pursued by Ford, Texaco, and Chrysler. A variation of this principle, embodying a prechamber device, is being studied by General Motors. These systems are still under development and are not expected to be available in production quantities for a number of years.

Ford, General Motors, and Chrysler have passenger car gas turbine programs. Chrysler states that its engine would meet the 1975 emission standards. However, the 1976 standards have not yet been demonstrated. Major problem areas include poor fuel economy at part load and poor acceleration characteristics. All manufacturers indicate that sizable production is not possible until the 1980 time period.

4. ENGINE MODIFICATIONS

Certain components of the 1975 emission control system, such as EGR and the catalytic converter, impose demanding requirements on the design of the carburetion and ignition systems with respect to response, precision, flexibility, and control characteristics. Accordingly, all of the major automobile manufacturers are actively pursuing the development of new or improved carburetion, ignition, and control devices for the projected 1975 emission systems.

The principal carburetion system modifications include altitude and ambient temperature compensation, and electrically heated chokes. At least three domestic manufacturers, Chrysler, Ford, and General Motors, are conducting in-house development work on electronically controlled fuel injection systems. A number of the foreign manufacturers already have these types of systems in production. With regard to ignition system modifications, the general industry trend appears to be toward the adaptation of electronic systems typified by Chrysler's breakerless, inductive design in which ignition coil current is switched by an electronic control unit in response to timing signals produced by a distributor magnetic pickup. The ultimate in projected 1975 engine system innovations is the electronic engine control system proposed by Chrysler, which would integrate the regulation of ignition timing and

EGR flow rate in response to engine speed, load, operating temperature, and certain transient conditions.

In general, the bulk of the durability emissions testing accomplished to date has been conducted on systems which incorporate considerably less than a full complement of the proposed engine modifications including innovative devices discussed by the manufacturers for their projected 1975 systems. The reason for this may be that many of these devices are still in the process of development. It seems likely that these modifications and devices will improve emission system performance and durability; however, it is not possible at this time to predict the degree of improvement that might be derived from their use.

5. EXHAUST GAS RECIRCULATION

The principal control of NO_x emissions in 1975 emission control systems will be accomplished by the use of exhaust gas recirculation (EGR), in which a portion of the exhaust gas is recycled into the engine to lower the temperature of combustion. All of the proposed 1975 EGR systems operate on the same basic principle, although the designs of the different manufacturers differ in a number of details. These include the location of the exhaust gas pick up, the point of introduction of the recycled gas into the engine induction system, the metering devices, and the signal source and associated control system.

While most manufacturers plan to continue with current types of EGR system designs through 1975, problems have been encountered with the plugging of orifices and/or sticking of the EGR flow control valves. These problems may ultimately demand design modifications to the systems projected for use in 1975, depending upon EPA decisions concerning the allowable maintenance that can be performed during certification testing.

6. OXIDATION CATALYSTS

With the exception of Toyo Kogyo, all of the manufacturers' first-choice systems incorporate an oxidation catalyst with air injection for the aftertreatment of HC and CO emissions in the engine exhaust. Toyo Kogyo's first-choice systems utilize a thermal reactor device. The key to the achievement of the 1975 Federal standards, therefore, lies with the successful development of an oxidation catalyst. However, many problem areas remain to be resolved, such as durability, emission performance uncertainties, catalyst contamination, and safety. Industry's status with respect to these problems and plans for their resolution will be discussed next.

6. 1 PROBLEM AREAS

6. 1. 1 Durability Problems

Oxidation catalysts pose fundamental durability problems due to inherent characteristics associated with the pellet alumina substrate or the monolithic ceramic substrate with alumina wash coat.

Catalyst durability is composed of two separate but interrelated aspects: emission durability and physical durability. Emission durability, or the ability to continue oxidizing HC and CO to the required levels throughout 50,000 miles, is most strongly impacted by decremental changes in catalytic activity or efficiency caused by:

a. Contamination from fuel and oil additives or compounds (e. g., lead, phosphorus, sulfur, etc.) resulting in "poisoning" of the catalytic material.

b. Reduced alumina porosity due to phase change at excessive temperature.

c. Alumina thermal shrinkage due to excessive temperature.

Physical durability, or the ability to maintain the substrate intact throughout 50,000 miles, is most strongly impacted by:

a. Thermal expansion differences between monolithic ceramic substrates and their supporting container.

b. Local melting of monolithic ceramic substrates due to overtemperature.

c. Failure of pellet retaining screens due to overtemperature.

d. Cracking of monolithic ceramic substrates and break up of pellet substrates due to vibratory loads.

6.1.2 Emission Performance

Representative best examples of emission performance data for catalysts produced by 12 different companies are shown in Table 2. These catalysts were tested in experimental systems which ranged from "conventional" passenger cars (with the addition of a catalytic converter) to laboratory prototype 1975 systems. Many catalysts (base metal or noble metal, pellet or monolithic) achieved HC and CO levels far below 1975 standards when fresh. However, when the catalysts are operated to extended mileages, the HC and CO levels tended to rise to levels exceeding the 1975 standards.

While a number of these catalysts met 1975 HC and CO standards at greater than 20,000 miles, the variation of vehicle test procedures (AMA durability runs, dynamometer runs, etc.) and the variation in test fuels and oils preclude a systematic assessment of the true capability of a given catalyst under projected EPA certification conditions. These conditions encompass the 50,000-mile EPA certification test specifications and the use of fuel with projected additive contaminant levels of 0.05 gm/gal lead (max.), 0.01 gm/gal phosphorus (max.), and conventional lube oils. Such an assessment can be made only with vehicles incorporating the full complement of 1975 emission control system components, tested in accordance with EPA certification procedures.

6.1.3 Catalyst Contamination

Oxidation catalysts are very susceptible to contamination from sources which can reduce or destroy catalytic activity. There is universal agreement that the catalytic efficiency of current automotive catalysts can be lost or reduced by reaction with, or blanketing by, lead, phosphorus, and sulfur in gasoline. However, there is a scarcity of actual test data to establish the actual poisoning mechanism and the particular amount of efficiency degradation attributable to a given contaminant level.

Table 2. Catalytic Converter Vehicle Test Results (Representative Best Examples)

Manufacturer (and Type)	Testing Co.	Test/Car No.	System Description		Emissions, gm/mi								Remarks
					Low Mileage				High Mileage				
			Noncatalyst Mods or Components	Catalyst Desig.	Test Mileage	HC	CO	NO_x	Test Mileage	HC	CO	NO_x	
Houdry (BP)	GM	61318	EM + AI + EGR	1259 JX3-1X1	0	0.25	2.9	1.9	21,178	0.87	4.1	1.6	Test continuing
Chemico (BP)	EPA	1971 Olds	—	2 beds		0.15	1.36	0.26					
Engelhard (NM)	Engelhard	351 V8	AI	PTX 433	500	0.16	0.52	–	35,821	0.35	3.0	–	Lead-sterile fuel over non-AMA durability cycle
		351 V8	AI + EGR	STD PTX5	380	0.32	2.1	<3	25,269	0.39	3.3	<3	
		351 V8	AI + EGR	IMP PTX 5	0	0.22	0.28	<3	12,030	0.24	2.6	2.2	
	Volvo	913	EM + AI + EGR	PTX 416	0	0.11	1.55	2.48	–	–	–	–	Catalyst failed at 29,900 mi
		1091	EM + AI + EGR	PTX 416	–	–	–	–	25,344	0.24	2.45	1.82	
	American Motors	D00-24	EM + EGR + AI	PTX 423-S	0	0.09[a]	1.5[a]	0.75[a]	50,000	0.32[a]	4.8[a]	2.1[a]	1970-type slow choke
	GM	61319	EM + AI + EGR	PTX-4	0	0.13	1.9	1.3	21,527	0.55	5.5	1.6	
		17934	AI	PTX 423-S	–	–	–	–	70,000	0.85	8.7	3.5	High speed tire test
	Ford	1A58D	EM + AI + EGR + TR	PTX 5.35 PTX 5.10	0	0.23[°]	3.11[°]	1.27[°]	25,000	0.75[°]	7.97[°]	1.64[°]	Ford 1975 durability program
W.R. Grace (BP)	GM	1246	EM + AI + EGR	DAVEX 117	0	0.27	1.7	2.9	–	–	–	–	
(NM)	Int. Harvester	161	AI	Spiral Substrate	0	0.46	5.1	4.5	16,000	0.46	6.85	4.0	
Matthey Bishop (NM)	Johnson-Matthey	Avenger	AI + EGR	AEC 3A	0	0.11	1.65	0.85	24,000	0.33	1.33	2.01	Lead-sterile fuel
	Volvo	467	AI	AEC 3A	100	0.19	1.56	3.32					
Monsanto (BP)	Saab	9/385	Elect. Inj. + AI	404	0	0.22	1.44	2.37	9,750	0.50	2.97	2.87	
	GM	61329	EM + AI + EGR	NBP-70194	126	0.47	4.0	1.1	5,550	0.55	8.8	1.1	
Oxy-Catalyst (BP)	GM	2541	EM + AI + EGR		9	0.17	2.7	2.2	10,245	0.91	9.5	2.3	
UOP (NP)	UOP	71 Ford 351		PZ-195	–	–	–	–	21,933	0.47	2.65	–	20% catalyst lost
(NM)	UOP	71 Chev		PZM-7711	0	0.38	1.65	–	–	–	–	–	
(BP)	GM	933	AI + EGR	PZ-4-214-R-14	0	0.19	1.8	2.4	46,301	0.78	11.7	2.1	
Kali-Chemie (BP)	Saab	7/301	Elect. Inj. + AI		0	0.22	2.85	1.02	5,900	0.25	3.63	1.96	
Degussa (BP)	Saab	12/301	Elect. Inj. + AI		0	0.19	2.11	1.66	2,580	0.74	15.7	2.5	Catalyst poisoned by phosphorus in fuel (4 PPM)
ICI (NP)	Brit. Leyland	Austin	AI		0	0.19	1.38	2.08	9,200	0.20	2.61	2.21	
AC-Delco (BP)	American Motors	D11-3	AI + EGR		0	0.23	1.47	2.12	–	–	–	–	
		D17-11	AI + EGR		0	–	3.4	1.9	32,000	0.51[a]	3.4[a]	1.9[a]	
	Int. Harvester	393	AI + EGR		0	0.35	4.56	3.11	20,000	0.51	8.76	3.0	

NOTES

1. 1975 CVS test procedures, except when indicated by [°]
2. Catalyst type symbol N = Noble metal; B = Base metal; P = Pellets; M = Monolithic
3. System mods or components: EM = Engine modifications; AI = Air injection; EGR = Exhaust gas recirculation

[a] Least-squares straight line value

[°] 1972 CVS-C test procedure

6.1.3.1 Lead Additives

The effect of lead contaminant level in the fuel on the efficiency of an Engelhard PTX 3 catalyst is illustrated in Figure 1. Although trends between the lead-free, 0.035 gm/gal, and 0.07 gm/gal levels can be established, the variability in the data precludes the establishment of an accurate correlation of catalyst efficiency vs lead level and test duration. It should be noted that these tests were conducted at constant engine speed and over a mild durability cycle, and as a result the data may not be directly applicable to catalysts installed in a vehicle and subjected to the EPA certification cycle. This becomes evident when the data in Figure 1 are compared with the durability data provided by other manufacturers, which generally indicate a rather gradual degradation of catalyst/system performance with mileage accumulation. This discrepancy points out the need for further systematic work in the area of fuel contaminant effects on catalyst performance.

6.1.3.2 Other Contaminants

Much less specific information is available concerning the deleterious effects of phosphorus and sulfur on catalytic activity. Saab-Scania reports "catalyst poisoning" with lead sterile fuel containing only 4 ppm phosphorus.

General Motors tests have been conducted with 0.02 gm/gal lead, 0.005 gm/gal phosphorus, and 0.03 percent sulfur. They have seen no "significant" differences in the effects of these contaminants on base metal catalysts as opposed to noble metal catalysts, although they feel that lead may be worse for base metals. General Motors states that the temperature range of 900-1200 °F normally seen in an automotive catalyst is the range where sulfur readily deposits on the catalyst surface. If the converter could be designed to operate above 1300 °F all the time, sulfur problems would be alleviated. General Motors feels that phosphorus effects are bad, regardless of the converter operating temperature. General Motors bench test data of an Oxy-Catalyst catalyst indicate that the sulfur build up on the catalyst is especially damaging to carbon monoxide reactivity.

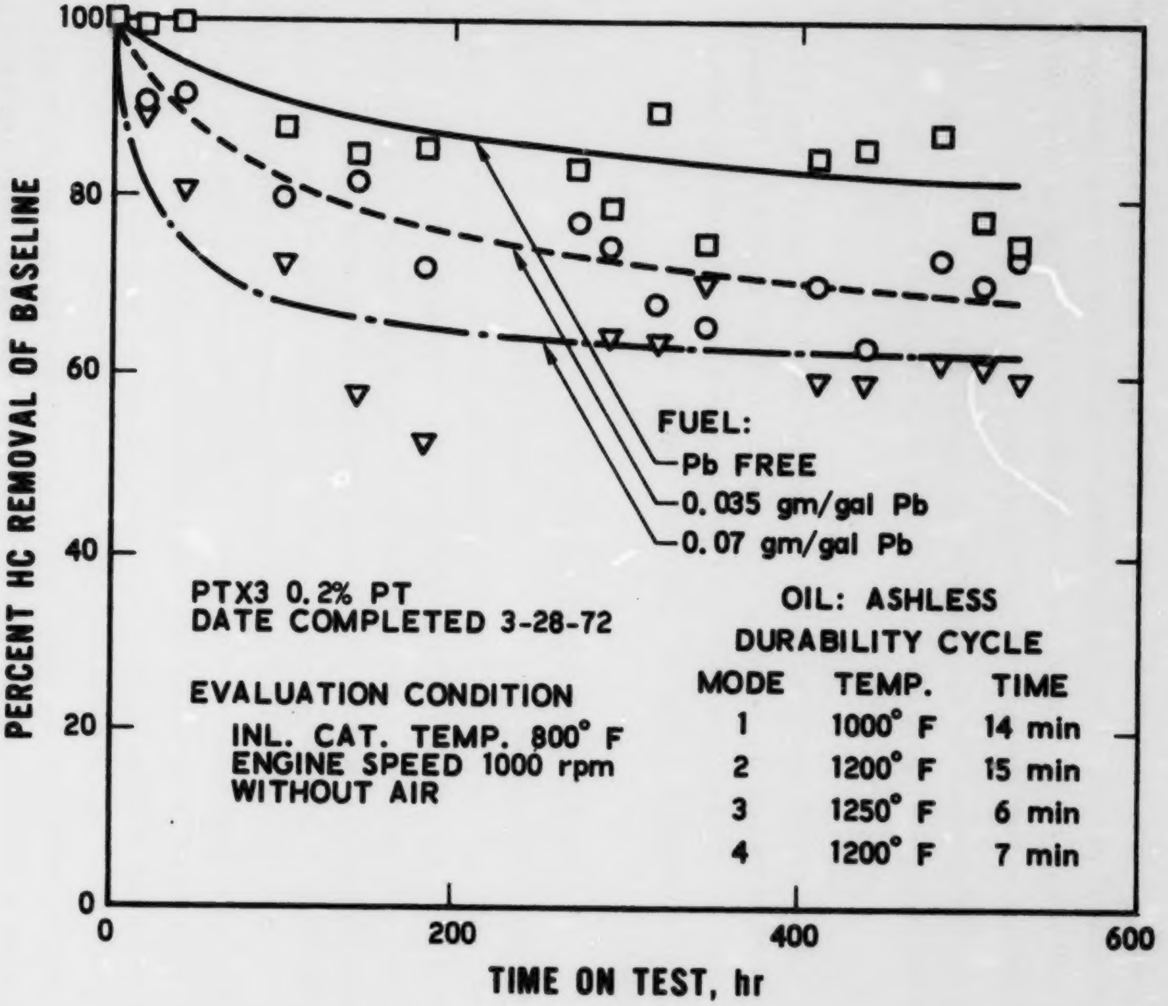


Figure 1. Effect of Lead Additive on Catalyst Efficiency

A chemical analysis by Ford of durability-tested catalysts revealed contamination from lead and phosphorus in the fuel and lubricants; zinc from lubricants; copper from an unknown source; and nickel, chromium, iron, and manganese from a thermal reactor manifold liner. Engelhard durability tests with unleaded gasoline (~0.03 gm/gal lead) resulted in the catalyst picking up substantial quantities of lead, zinc, phosphorus, and barium. Engelhard associates the zinc and barium with motor oil.

Matthey Bishop feels the hydrocarbon efficiency deterioration of one of their catalysts was due to phosphorus picked up from the engine oil.

6.1.4 Safety

Physical failure of either monolithic or pellet catalytic converters due to either overtemperature conditions or rupture of the canister could cause vehicle fires, posing a serious vehicle safety hazard. Currently, there are insufficient data available to evaluate safety aspects of catalytic converters.

6.1.5 Technology Uncertainties

Oxidation catalyst technology is rapidly changing through intensive product design modifications, as well as through comprehensive test and evaluation programs, in both the catalyst industry and the automotive industry. Because of these rapid changes, the emission data frequently reported as "latest" results are based on catalyst materials and substrates which may in fact be "old technology" previously discarded by others. Due to the time delay inherent in the relationship between the substrate-catalyst-converter suppliers and the automakers themselves, it is not surprising that some problems reported as "severe" by one company are treated as "solved" by others. Some of the recent data presented by the catalyst makers with their latest technology have indicated encouraging results at relatively high mileage; however, it remains to be seen whether these catalysts can maintain good performance when tested in a prototype emission package under realistic driving conditions by the automobile manufacturers.

6.2 INDUSTRY PLANS FOR RESOLUTION OF PROBLEMS

6.2.1 Contamination Control

The Administrator of EPA has proposed to limit the lead content of gasoline to 0.05 gm/gal and the phosphorus content of gasoline to 0.01 gm/gal for the unleaded grade of gasoline to be made available for automobiles utilizing catalytic converters. A similar regulation of the sulfur content in such unleaded grade will also be promulgated if the auto companies can present substantive evidence to establish the needed level.

All parties agree that zero levels of contaminants would be desirable, but practical considerations, such as lead contamination in shipment, and the need for phosphorus additives used in detergent or carburetor cleaning solutions, dictate that trace levels of these contaminants will have to be "tolerated" by the catalysts, at least in the immediate future.

The exact contribution of lubricating oil constituents to catalyst deactivation is not evident. Ashless oils would certainly help to ensure minimization of this contaminant but such oils have not been widely evaluated and could adversely affect other engine parts. At present there is no clear picture of whether or not to regulate lubricating oil composition. Therefore it would appear that near-term automotive catalysts would have to tolerate conventional lubricating oils.

6.2.2 Increased Catalyst Activity

An obvious approach to improving the ability of emission control systems with oxidation catalysts to meet the 1975 standards is to increase the catalyst activity. This is particularly true with regard to lowering the light-off temperature, inasmuch as the sooner the catalyst is active after start up, the lower the cold start emissions. It would be expected that all catalyst suppliers would be actively pursuing such technological advancements to gain a competitive advantage.

For example, in this area, Engelhard has recently related progress in improving the catalytic activity and thermal stability of PTX-type monolithic catalysts. Comparison of standard versus improved PTX catalysts shows the improved PTX catalyst has greatly increased retention of activity for carbon monoxide and olefinic hydrocarbon oxidation even after severe thermal aging. Johnson-Matthey, another proponent of noble metal/monolithic catalysts, also has reported similar progress in improved catalytic activity and high-temperature thermal stability. Both manufacturers report reductions in light-off temperature of approximately 180-250 °F.

General Motors, currently a base metal/pellet proponent, has presented data which indicate a basic difference in activity characteristics between base and noble metal catalysts. They point out that the base metal catalyst starts conversion at a lower temperature than the noble metal type and the level of conversion gradually increases as temperature increases. On the other hand, the noble metal catalyst exhibits a rapid increase in conversion efficiency once a threshold temperature is reached (this is shown in Figure 2).

Engelhard, General Motors, and Matthey Bishop presented data showing that prolonged exposure of noble metal catalysts to elevated temperature would result in a gradual decrease of catalyst activity with increase in soak temperatures in the range of 1200-2000 °F. Similar data for base metal catalysts by General Motors, however, indicate no significant deterioration in catalyst activity in the temperature range between 1200 and 1500°F.

6.2.3 Overtemperature Protection Systems

Overtemperature protection systems of several types are proposed to prevent overheating of the catalyst bed, overheating of the vehicle structure, and vehicle and external fires. Two basic approaches have been suggested by the automotive industry and are under evaluation for providing the necessary catalyst overtemperature protection. Both approaches employ a thermocouple signal to actuate the control device.

One method is to control the secondary air supply to the catalytic converter. Without the necessary oxidizing atmosphere, the catalyst would not function efficiently and generate the normal temperature rise across the bed. The

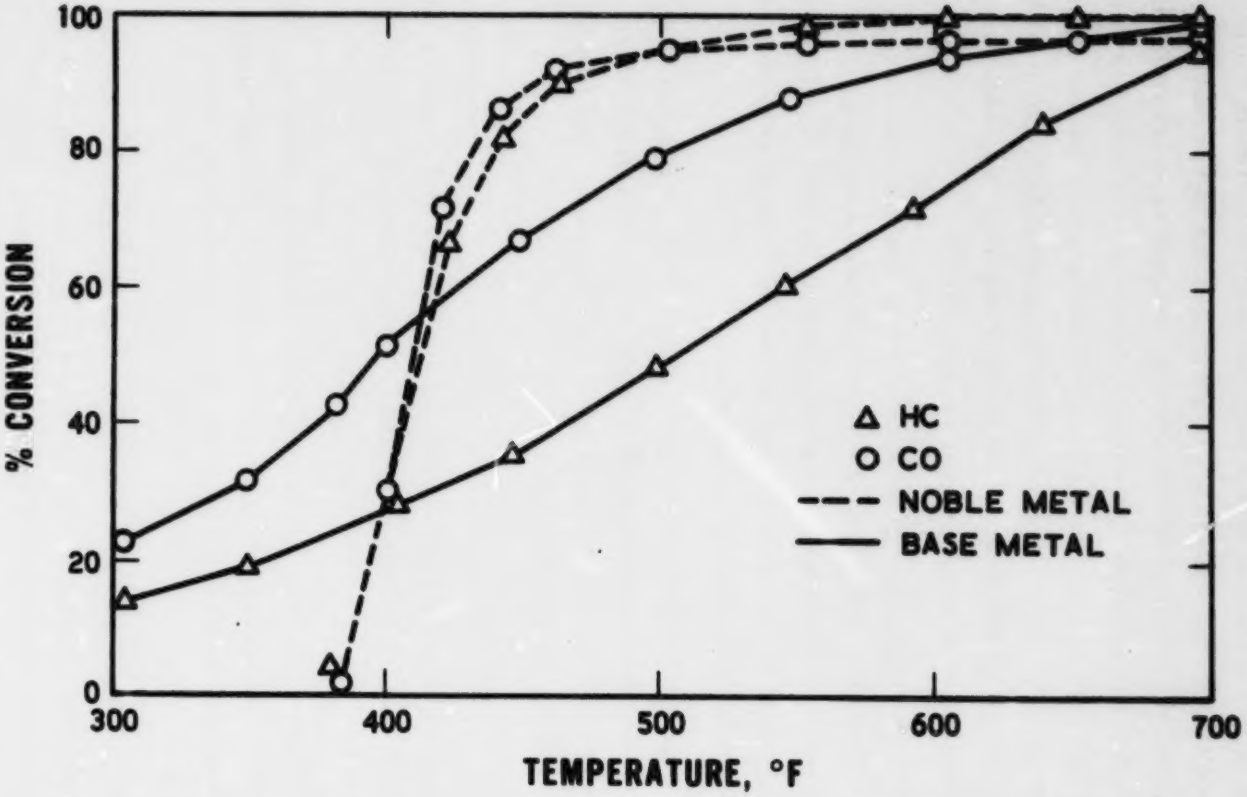


Figure 2. Conversion Characteristics of Base Metal and Noble Metal Catalysts (Standard Bench Test Evaluation)

other method is to completely bypass the exhaust gas around the catalytic converter whenever a certain temperature, say 1500 °F, is exceeded. This approach would fully protect the catalyst (if actuated in time), whereas the first approach still exposes the catalyst to the gas temperature of the exhaust flow. Current opinions of the various companies relative to the type of over-temperature protection system proposed for 1975 vehicles vary widely. Chrysler is developing a full by-pass system, Ford plans to have secondary air control, Nissan is considering both approaches, General Motors plans to incorporate a choke which fails in the open position, and Volvo and British Leyland plan to have a warning system only.

In addition to these two protection system approaches, other refinements/devices are also being considered, including placement of the converter further downstream from the exhaust manifold to reduce inlet gas temperatures, and the use of an air dump valve during periods of vehicle deceleration to minimize the catalyst bed temperature.

With regard to vehicle structure protection, heat shields are proposed for use between the converters and the vehicle. General Motors proposes insulators on top and bottom of their converter to protect against vehicle overheating as well as grass fires.

6.2.4 Attrition Control

Advances in both catalyst substrate properties and canister design features are required to meet the durability requirements of the 1975 emission standards.

Early pellet substrates were subject to severe breakup or attrition, as well as thermal shrinkage. Data from a number of manufacturers indicate that pellet attrition has been substantially reduced and further improvements may be possible.

Similarly, Engelhard has described improved catalyst properties leading to increased high-temperature activity which may result in improved durability of the alumina wash coat of the monolith catalyst.

The wide spectrum of catalytic converter mechanical failure types and modes experienced to date illustrates clearly that the canister (or container) design must protect the ceramic substrates (pellet or monolith) from excessive vibratory loads and stresses. In view of the inherent fragility of ceramics, such failure can be ascribed to deficiencies in the canister support design.

Aside from General Motors (AC-Delco) and Universal Oil Products (Mini-Verter), most companies had exceedingly poor results with pellet converters. For example, Chemico requires pellet addition (due to attrition) at 3000- to 8000-mile intervals.

General Motors claims that its horizontal-bed converter design, in combination with thermal shrinkage improvements in the pellet substrate, has solved the attrition problem. If so, the internal pellet support arrangement (top and bottom retaining screens, etc.) is such as to accommodate the relative thermal expansion of the pellets, retainers, and canister shell while holding the pellets in sufficiently close-packed proximity to prevent vibratory movement of the pellets against each other.

Early monolithic converters apparently were little more than a sheet metal canister, housing the ceramic core. In such an arrangement, it would be expected that differential thermal expansion and vibratory loads would severely damage the catalyst, as has been evidenced. A number of promising design approaches, however, have been advanced for solving these problems. These include shock mounting of the core in the canister, compensating for differential thermal expansion, and preventing axial movement between core and canister.

6.2.4 Platinum Availability

The question of platinum availability has been an issue of concern for some of the automobile and catalyst manufacturers. A recent study conducted by Johnson-Matthey, which is associated with Rustenburg Platinum Mines, Limited, a major producer of platinum in the Western world, has indicated that sufficient platinum will be available to satisfy the combined demand of the automotive industry and all other platinum users. Engelhard has also stated previously that adequate platinum supplies will be available to satisfy the demands of the automotive industry provided that platinum from used catalysts is recycled.

7. THERMAL REACTORS

The thermal reactor is a high-temperature chamber which replaces the conventional engine exhaust manifold. Hot exhaust gases from the engine enter the thermal reactor, which is sized and configured to increase the residence time of the gases and permit further oxidation reactions, thus reducing the HC and CO concentrations.

Whereas both rich and lean reactors have been considered and evaluated for use in 1975 emission control systems, all of the reactors presently being tested by the automobile manufacturers as potential 1975 candidate devices are designed for fuel-rich engine operation. These systems require the addition of secondary air (usually injected at the engine exhaust port) to enhance the oxidation reactions in the reactor.

With the exception of Toyo Kogyo, no manufacturer proposes to use a full-size thermal reactor device as a first-choice system component for 1975. The General Motors and Chrysler systems utilize a partial (i. e., a small, simplified) reactor which serves primarily as a quick-heat device for rapid warmup of their catalytic converter. The Toyo Kogyo reactor is a prime emission control component of its rotary engine system; in addition, the reactor is one of several systems being evaluated for use on its 1975 reciprocating engine. Several manufacturers are evaluating reactor devices as 1975 alternate system components.

Thermal reactor problems identified by the various manufacturers encompass the following: lack of sufficient emission control capability, packaging difficulties, excessive underhood temperatures, and lack of sufficient reactor and secondary air injection system durability. In addition to these problems, severe engine damage has been caused by reentry of metal oxide particles from the reactor core material through the EGR system into the engine lubricating oil. A recent study by Ford implies that an incompatibility may exist between thermal reactors and catalytic converters when used together. Material deposits have been found in the catalyst which are thought to originate in the reactor liner. These deposits may contribute to the excessive deterioration observed in a number of thermal reactor/catalytic converter emission control systems.

8. SECONDARY AIR SUPPLY

Although secondary air injection at engine exhaust ports has been widely used as an independent control device for the suppression of HC and CO emissions since 1966, it is not being given serious consideration by any automobile manufacturer as a sole system for meeting the 1975 standards.

In aftertreatment devices for HC and CO control, such as catalytic converters and thermal reactors, sufficient oxygen is needed to promote oxidation of the pollutants. The oxygen required is provided by secondary air supplied by an engine-driven air pump.

Generally, little more than passing mention of the use and type of air pump was made by the automobile manufacturers in discussing their projected 1975 emission control systems. Pump durability and pump noise are frequently identified as problem areas; the durability problem appears to be particularly troublesome. However, no manufacturer classifies any part of the air injection system as critical for 1975.

9. EMISSION GOALS

9.1 GENERAL

In order to comply with the 1975 emission standards on production vehicles at 50,000 miles, the automobile manufacturers must demonstrate substantially lower emission goals on low mileage engineering prototype vehicles to account for a number of parameters affecting emission control system performance. These parameters include the emission control system deterioration factor (DF), the prototype-to-production slippage factor (PPS), and, in case emission averaging is not permitted, the production quality control factor (QCF). Based on these definitions, the low mileage emission goals for engineering prototype vehicles are computed from the following equation:

$$M_{goal} = \frac{M}{DF \times PPS \times QCF}, \text{ gm/mi}$$

where M represents the 1975 HC, CO, and NO_x emission standards and DF represents the system deterioration factor between low mileage and 50,000 miles. To minimize "green" engine/control-system effects, EPA has selected the 4,000-mile point as the low mileage reference value. It should be noted that deterioration factors must be used with care. In general, deterioration factors determined for one type of vehicle/emission control system are only applicable to similar configurations.

The in-house emission goals established by the various manufacturers for reciprocating spark ignition engine-powered vehicles are presented in Table 3. Also shown are the emission goals selected by Toyo Kogyo and Mercedes-Benz for rotary engine-powered vehicles. Mercedes-Benz has stated that the 220D diesel vehicle will probably meet the 1975 standards but did not provide emission goals for diesels. With the exception of one set of numbers presented by General Motors, the emission goals established by the automobile manufacturers are based on the emission averaging concept (QCF = 1.0). Another set of emission goals presented by General Motors is listed in the table. This set is based on the assumption that 99.5 percent of the production vehicles meet the 1975 standards at 50,000 miles. This assumption results in such extremely low HC and CO emission levels that it is doubtful whether these values can be attained with current spark ignition engine emission control system technology.

Table 3. Summary of Low Mileage Emission Goals for Projected 1975 Control Systems

Selected Manufacturers	Emission Control System	Emission Goals gm/mi		
		HC	CO	NO_x
American Motors	EM+EGR+AI+OC	0.10-0.15	1.50-2.55	2.2
General Motors				
(No catalyst change)	EM+EGR+AI+PTR+OC	0.2	1.7	2.07
(Catalyst change, 25,000 mi)	Same	0.27	2.27	2.07
(99.5% of cars meeting standard at 50,000 mi)	Same	0.07	0.71	1.16
Foreign Manufacturers				
IC engine, catalyst (and thermal reactor)	EM(+EGR)+AI+(TR)+OC	0.14-0.2	1.2-2.0	1.2-2.3
IC engine, thermal reactor (reciprocating and rotary)	EM(+EGR)+AI+TR	0.26-0.29	2.2-2.3	2.0-2.3

AI = Secondary air injection
EM = Engine modifications
EGR = Exhaust gas recirculation
TR = Thermal reactor
OC = Oxidation catalyst
PTR = Partial thermal reactor

Most manufacturers have assumed HC and CO emission deterioration factors of 2.0 for systems incorporating catalytic converters. Based on the available test data, this assumption appears too optimistic, although further improvements in the carburetion, choke, and ignition systems, and in catalyst performance might be achieved in time for use in 1975 vehicles. Toyo Kogyo has selected a HC and a CO deterioration factor of 1.3 for systems incorporating a thermal reactor only. This is a lower factor than that selected for its systems incorporating a catalytic converter. NO_x deterioration factors assumed by the manufacturers vary between 1.1 and 1.8. It is believed that these levels are attainable, although EGR system maintenance may be required to accomplish this.

The emission goals presented by the automobile manufacturers are based on the ground rule that catalyst replacement is not permitted during the 50,000-mile test. If catalyst replacement were permitted at intermediate mileage points, the emission goals could be relaxed somewhat. The degree of relaxation is primarily determined by the shape of the emission-versus-mileage curve which is generally different for different vehicle/control system combinations. General Motors is the only manufacturer that has provided emission goals for 25,000-mile catalyst replacement intervals.

9.2 DETERIORATION FACTOR

The deterioration factor (DF) of the emission control system is primarily responsible for the manufacturer's stringent emission goals. This factor accounts for the emission increase which results from the performance degradation with mileage accumulation of all components utilized in the system including the engine, the catalyst, and other aftertreatment devices. In general, the catalytic converter is the critical component. Catalyst degradation is the result of poisoning of the active elements by lead, phosphorus, sulfur, and oil additives, and of attrition and exposure to overtemperature conditions. Those manufacturers considering thermal reactor systems expect their deterioration factors to be lower than those of catalyst systems.

Many of the high mileage tests of emission control systems incorporating a catalyst indicate a rather gradual deterioration of emission performance with mileage accumulation. This is illustrated by most of the HC and CO data provided by American Motors, General Motors, Engelhard, and Ford and by the HC data presented by Matthey Bishop. These data suggest that deterioration factors derived for a particular vehicle/control system are only valid for similar configurations and operating conditions. For example, the deterioration factors derived from a catalyst system operated under idealized conditions (lead-sterile fuel and moderate catalyst temperature) are not necessarily applicable to similar vehicles which are subjected to commercially available "lead-free" fuel and/or more severe durability or customer driving patterns.

Test data provided by Ford from the 1974 California catalyst-only vehicle fleet indicate rapid degradation of the emissions during the first few thousand miles on two of the five vehicles. In both instances the emissions remained essentially constant from this mileage point up to 50, 000 miles. This trend is contradictory to other Ford durability data.

The deterioration factors derived from the high mileage emission data provided by the automobile manufacturers are summarized in Figure 3. Although it is not possible to precisely correlate these data, it is apparent that the degradation has generally been more severe for systems with low initial (low mileage) emissions.

Since the emission control systems projected for use in 1975 vehicles will incorporate improved carburetion, choke, and ignition systems as well as improved (stabilized) catalytic converters, the emissions and the deterioration factors of these systems should be lower than currently indicated. It appears that this assumption was included in the considerations made by the automobile manufacturers in establishing their deterioration factors.

9. 3 PROTOTYPE-TO-PRODUCTION SLIPPAGE FACTOR

The prototype-to-production slippage factor (PPS) is defined as the ratio of the average emissions of production vehicles compared with the emissions of identical engineering prototype vehicles. Based on past experience, the emissions from production vehicles are on the average higher than those of the prototype because of production tolerances and adjustments made in the final design and fabrication of certain components. Although these factors are known for current vehicles, it is difficult to make accurate predictions for future designs. Most of the manufacturers project PPS factors between 1. 1 and 1. 25.

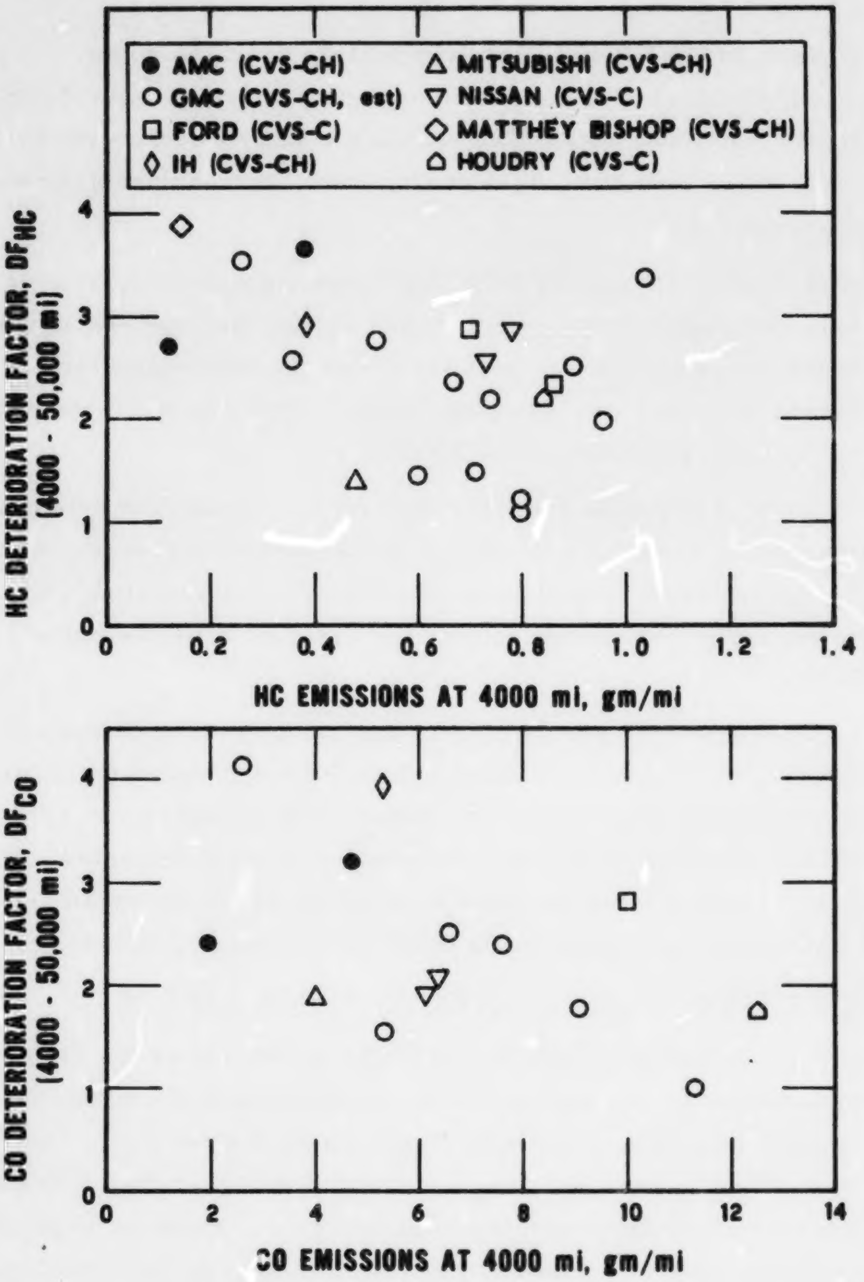


Figure 3. Deterioration Factors vs Emissions at 4000 Miles

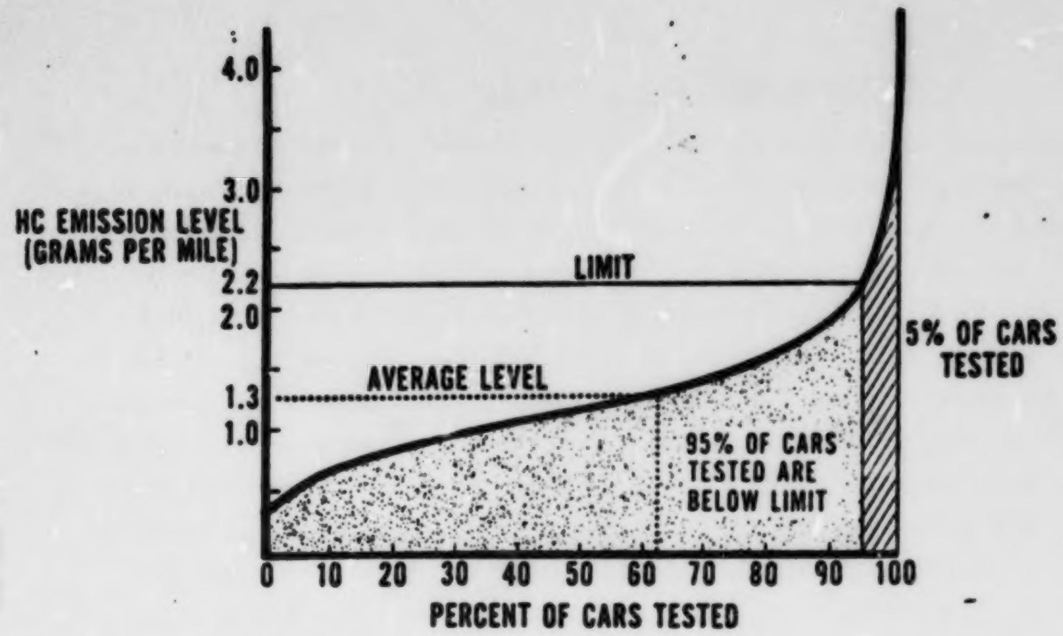
9.4 PRODUCTION QUALITY CONTROL FACTOR

The production quality control factor (QCF) accounts for the differences between the average emissions of a certain vehicle model and the maximum emissions of a specified percentage of the total vehicle population of that model. The effect of the QCF on the emission goals is illustrated in Figure 4, which shows the HC and CO emission distributions from 1971 General Motors production vehicles. Although these curves may not be applicable to 1975 model vehicles, they are presented here to show trends. As indicated, extremely low emission goals would be required if a high percentage of the vehicles would have to meet the standards. For example, a QCF of approximately 2.8 for HC and 3.1 for CO would be required to achieve compliance with 99.5 percent of General Motors vehicles in Figure 4. This results in correspondingly tighter emission goals. Conversely, if the emission averaging concept is adopted, the QCF has no effect on the emission goals (QCF = 1.0).

10. INTERIM STANDARDS

All thirteen automobile manufacturers appearing as witnesses at the EPA Suspension Request Hearings have asked for a one-year suspension of the 1975 Federal emission standards and adoption of less stringent interim standards. In justifying their request, the automobile manufacturers contend that the technology is currently not available to achieve the 1975 standards on spark ignition reciprocating engine-powered production vehicles. Furthermore, the automobile manufacturers are extremely reluctant to mass produce a catalytic emission control system without having successfully demonstrated vehicle/control system safety, performance, and durability. To date, there are no data available that prove that mass-produced vehicles can meet the 1975 emission standards at 50,000 miles when operated under conditions simulating customer driving patterns.

The interim standards proposed by the automobile manufacturers and a number of the catalyst suppliers are presented in Table 4. All of these interim



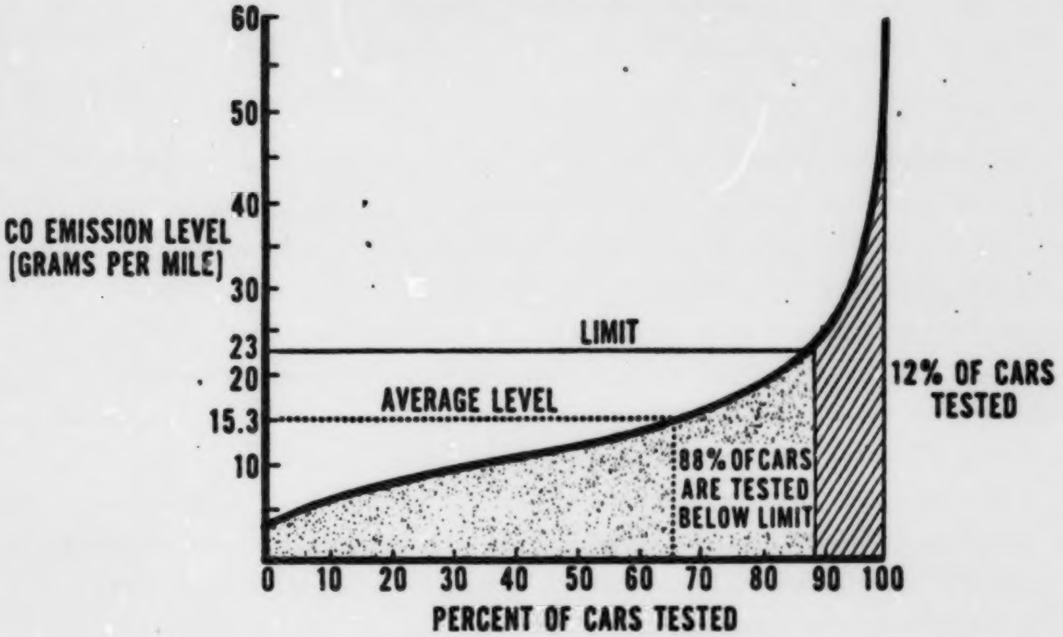


Figure 4. HC and CO Emission Levels from 1971 California Car Production Audit (1473 Cars Tested) (GM Production Vehicles)

Table 4. Interim 1975 Emission Standards Proposed by Manufacturers

Manufacturer	Emission Control Concept	Emissions, gm/mi HC	Emissions, gm/mi CO	Emissions, gm/mi NO_x	Manufacturers' Remarks
I. DOMESTIC AUTOMOBILE MANUFACTURERS					
American Motors	Engine Modification	3.4	39	3.0	1974 Standards
Chrysler	Engine Modification	1.5 to 2.0	20 to 25	2.5 to 2.0	To be selected within that range
Ford	Oxidation Catalyst	1.6 1.5	19 19	2.0 3.1	Some models possibly without catalyst
General Motors	Engine Modification	3.4	39	3.0	1974 Standards
International Harvester	Oxidation Catalyst	1.0 to 1.15	12 to 20	3.0 to 1.75	Either combination feasible
II. FOREIGN AUTOMOBILE MANUFACTURERS					
British Leyland	Engine Modification	3.4	39	3.0	1974 Standards
Daimler-Benz	Engine Modification	1.5	20	1.5	
	Diesel Engine Without Catalyst	0.41	3.4	3.1	Meets 1975 Standards
Nissan	Engine Modification	3.4	39	3.0	1974 Standards
Saab-Scania	Engine Modification	3.4	39	3.0	1974 Standards
Toyo Kogyo	Engine Modification	–	–	–	Not selected
	Rotary Wankel Engine With Thermal Reactor	(0.41)	(3.4)	(3.1)	Good chance to meet 1975 Standards
Toyota	Engine Modification	3.4	39	3.0	1974 Standards
Volkswagen	Engine Modification	3.4	39	3.0	1974 Standards
Volvo	Engine Modification	3.4	39	3.0	1974 Standards
III. CATALYST MANUFACTURERS					
Chemico	Catalyst Addition	Technology to meet 1975 standards available			No test data supporting claim
Engelhard	Catalyst	1975 Standards or slightly higher			
W. R. Grace	Catalyst	0.6 to 0.8	7 to 10	–	
Universal Oil Products	Catalyst	0.96	7.99	–	

standards are based upon the concept of emission averaging and, in the case of Ford, upon the satisfactory resolution by EPA of several regulatory issues, including fuel specifications, vehicle maintenance, and special allowances for methane in the exhaust. Ford proposed that the hydrocarbon composition of the exhaust should be considered in evaluating vehicle compliance with the standard. The methane reactivity was specifically mentioned, since methane's role in the smog formation process is negligible. Methane conversion efficiency of the catalyst is low, compared with other more reactive hydrocarbons. If reactivity were considered, catalysts would appear to be more effective in reducing hydrocarbons in the exhaust.

With the exception of Ford and International Harvester, which propose to use oxidation catalysts, the remaining automobile manufacturers' suggested interim standards will be achieved by engine modifications, including improved carburetion, choke, and ignition systems.

With the exception of Chrysler, Ford, International Harvester, and Daimler-Benz, all automobile manufacturers have proposed to adopt the 1974 emission standards for 1975 spark ignition reciprocating engine-powered vehicles, primarily for the following stated reasons:

a. Promulgation of interim standards lower than the 1974 standards has little effect on improving air quality, as shown by the National Academy of Sciences.

b. Adoption of more stringent standards would tend to dilute current emission control system development efforts because the automakers might then be inclined to select 1975 systems using devices such as thermal reactors, which have little chance of ever meeting the 1976 NO_x standard.

c. Excessive risk and system cost.

The interim standards proposed by Chrysler and Daimler-Benz are of the order of 50 percent of the 1974 standards. Both companies would attempt to achieve these levels by means of engine modifications only, possibly with the use of secondary air injected into the exhaust manifold. This basic approach is considered to be desirable because it minimizes the raw engine emissions.

As a result, potential catalyst heat load problems will be reduced in future systems incorporating catalysts.

Ford and International Harvester propose interim standards somewhat below those recommended by Chrysler and Daimler-Benz. Both Ford and International Harvester project the use of oxidation catalysts in their interim system vehicles but Ford believes that the catalyst might be omitted on some Ford models. In this case, catalytic systems could be introduced more gradually to gain the required field experience and to minimize the risk. Since the emissions from the Ford 1972 and 1973 development fleets and the raw engine emissions from the Ford Riverside fleet are substantially lower than the 1974 standards, the prospects appear favorable for this approach. To further investigate this matter, a review was made of 1972-73 certification test data from American Motors, Ford, General Motors, and Nissan. Adjustments were then made to these data to account for emission deterioration, production slippage and, where applicable, conversion to the 1975 test procedure. Based on the resultant analysis, it appears that the following emissions can be achieved with available 1972 technology without the use of a catalyst: 2.5 gm/mi HC, 2.5 gm/mi CO, and 3.0 gm/mi NO_x, respectively.

With the likelihood of further emission reductions resulting from carburetor and ignition system improvements, it is believed that emission standards more stringent than the 1974 standards are feasible for 1975. Further emission reductions are possible by incorporation of catalysts currently under development. Even with conservative estimates of catalyst efficiencies at 50,000 miles, the HC values shown above could be reduced by approximately 30 percent and the CO values by about 40 percent, respectively. This assumes no replacement of the catalyst. If catalyst replacement at 25,000 miles is considered, the above percentage reductions would be changed to approximately 55 percent and 60 percent for HC and CO, respectively.

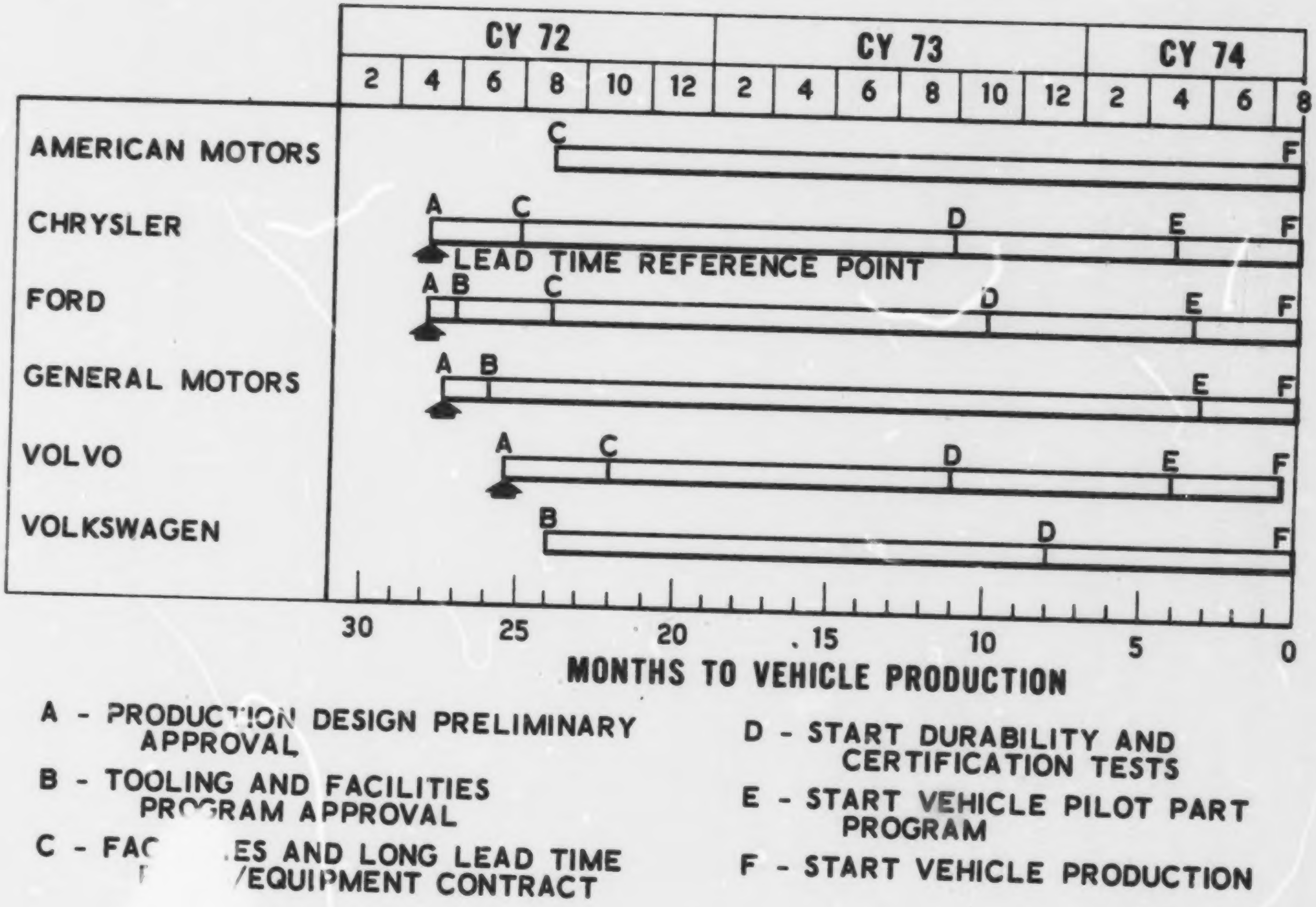
Catalyst replacement at 20,000 or 25,000 miles has been discarded by Ford on the basis of data which lead it to believe that catalyst deterioration is primarily confined to the low mileage range. However, the Ford position appears questionable in view of the vehicle durability test data submitted by American Motors, General Motors, Matthey Bishop, and other data from Ford. Most data from these manufacturers indicate a rather gradual emission and catalyst effectiveness deterioration with mileage accumulation. None of the other manufacturers has provided information regarding catalyst replacement between 0 and 50,000 miles.

11. PRODUCTION LEAD TIME

Each automobile manufacturer has identified one or more factors which control or define his lead time requirement for the development of production tooling and facilities needed to mass produce 1975 emission control system components. In each case, the most critical items cited were the fabrication of the catalytic converter and the completion of durability tests currently being conducted for the verification of the complete emission system design.

Since the catalytic converter appears to be a pacing production development item with which all of the manufacturers must contend, it serves as a consistent basis for examining and comparing production schedules and lead times among the different manufacturers. The data available for this comparison are shown in Figure 5. In general, the agreement of the catalytic converter production milestones among the various automobile manufacturers is good; the overall lead time requirements range from 25 to 28 months.

If the lead time reference point is fixed at the date of firm commitment, it is seen that the lead times estimated to be required by the various catalyst suppliers vary in a narrow range from 21 to 25 months. Allowing for the fact that production catalysts must be available at the manufacturer's plant in advance of first vehicle production, the automotive manufacturer's lead time requirement would be expected to be approximately 2 years. This is consistent with the previously noted lead time requirements of 25 to 28 months cited by the automobile manufacturers. Since the schedules of the automotive manufacturers are in good general agreement, it is concluded that there are no gross



[illegible]ure 5. Significant Milestones for Catalytic Converter Production (Data Supplied by Automobile Manufacturers) inconsistencies among or between the lead time specifications of the suppliers and manufacturers.

Ford has contracted with Engelhard Industries for supplying catalysts to be used in the Ford emission control system and has provided financial backing of up to $4.9 million for facilities and equipment. This relationship represents the only case to date of a contractual commitment between an automobile manufacturer and a catalyst supplier for production facilities.

All manufacturers have indicated that their current schedules represent an accelerated work effort in order to develop production facilities in time for the 1975 model year. Additional schedule compression holds higher risks for the automobile manufacturers because of the resulting major reductions in the time allowance set for correcting problems in production hardware design or assembly line operations; this effect is only correctable to a degree through the use of labor on an overtime basis, which in turn raises product cost. Some catalyst suppliers have estimated an ability to further compress their schedules by 3 to 6 months, but with corresponding increases in unit costs from 3 to 12 percent.

12. MAINTENANCE, SAFETY, AND COST

Recognizing that the 1975-1976 emission goals may never be effectively achieved unless emission control systems maintain their efficiency in service, EPA has indicated that they would consider approving increased maintenance of the emission system components under certain guidelines. Difficulty in meeting the 50,000-mile requirement has led to the consideration of permitting more maintenance and repair over the durability test mileage, provided that failure or deterioration of the component would, by appropriate design, "induce" the car owner to have the defect remedied. This approach is fundamentally difficult to implement because many types of emission control system failures tend to improve vehicle performance and driveability. Proposed fail-open modes for the EGR valve are found to pose safety hazard problems, while the cost of catalyst replacement tends to militate against the success of an approach permitting voluntary refurbishment of the system. In summary, no effective approach has yet been found to ensure that emission systems will continue to function properly in service.

Safety issues concerned with the 1975 emission control systems include poor passing performance, increased fire hazard, and possible catastrophic failures of critical vehicle components due to increased underhood and exhaust temperatures associated with the thermal reactor and/or catalytic converter. The performance problem has led a number of manufacturers to consider dropping low-power economy models in order to retain safe driveability throughout their product line. Currently, no one using the overtemperature-controlled catalytic converter by-pass valve is confident that it represents a satisfactory solution to the fire hazard problem.

The major cost factors associated with the 1975 emission control system package relate to increases in the purchase price of the car, increases in vehicle lifetime maintenance costs, and increases in fuel costs. Projections of sticker price increases for 1975 emission system cars (using a 1968 baseline) range from $255 to $412 among the various domestic manufacturers.

13. REGULATORY PROBLEM AREAS

In developing engineering goals for the 1975 emission control systems, the automobile manufacturers had to make a number of assumptions related to vehicle durability and to certification test procedures. These assumptions, which require action by EPA, include emission averaging for certification and assembly line vehicles, fuel contaminant regulation, methane allowance, and maintenance, warranty, and recall procedures.

All manufacturers have assumed that emission averaging will be permitted by EPA for both certification and assembly line vehicles. It is the consensus of the industry that meeting 1975 emission standards with every vehicle is not practical because of variations in the production tolerances and the test data.

A number of manufacturers have recommended that the fuel contaminant levels be limited to values below those permitted by the proposed EPA fuel additive regulations in order to prevent catalyst poisoning. In addition, the establishment of maximum sulfur and other additive levels in fuel is considered desirable. Test data by General Motors indicate that catalyst damage occurs with fuels containing more than 0.02 gm/gal lead, 0.005 gm/gal phosphorus, and 0.03 percent sulfur. Test fuel volatility is another important issue which deserves consideration by EPA. As shown by General Motors, modifications in the fuel volatility can result in substantial reductions of CO emissions during the cold start phase of the certification cycle without adversely affecting vehicle driveability. Since methane is essentially nonreactive, Ford proposes establishment by EPA of a methane allowance in interpreting HC emission test data. This approach would be particularly significant for control systems using platinum catalysts since the methane conversion efficiency of these catalysts is generally low.

The question of what constitutes a meaningful certification cycle for vehicle/control systems utilizing a catalyst has been raised by a number of automobile manufacturers. Chrysler has stated that the catalyst temperatures achieved during the EPA certification cycle are substantially lower than those obtained under high-load and/or customer driving conditions. As a result, vehicle/control system safety and catalyst durability cannot be adequately evaluated with the current certification procedure.

1. INTRODUCTION

The purpose of this report is to present a compilation and evaluation of all available information pertaining to the assessment of the technological progress by the automotive industry toward meeting the 1975 Federal emission standards for light duty vehicles. These 1975 standards are:

HC (hydrocarbons)	0.41 gm/mi
CO (carbon monoxide)	3.40 gm/mi
NO_x (oxides of nitrogen)	3.10 gm/mi

To fulfill the objectives of this study, the work effort was composed of two areas: data compilation and data review, summarization, and evaluation. A compilation was made of all information available from three sources: (1) the manufacturers' applications for suspension of the 1975 emission standards, (2) the testimony and supplementary material presented by the witnesses at the April 10-28, 1972 EPA Suspension Request Hearings, and (3) the documents submitted by industry in response to the September 1971 EPA technology survey questionnaire. A review, summarization, and evaluation of all data acquired were performed. First-choice emission control systems, possible alternate systems, unconventional engine designs, and emission control system components were included in the study. Emphasis has been directed toward low and high mileage emissions; component and system durability characteristics--in particular, catalytic converters; and factors affecting emission goals and interim standards. In addition, the problem areas related to the emission control systems and components were identified and the manufacturers' plans for resolution were evaluated.

The body of the report is based on information obtained from the automotive industry, including domestic and foreign automakers, catalyst manufacturers, and catalyst component suppliers. The appendix includes the highlights of the statements made by nonautomotive industry witnesses at the April 10-28 EPA Suspension Request Hearings.

2. CANDIDATE 1975 EMISSION CONTROL SYSTEMS

2.1 SUMMARY DISCUSSION

The discussion of candidate 1975 emission control systems presented in the following sections of this report is based on information from three sources: the manufacturer's applications for suspension, the testimony and supplementary material presented at the April 10-28 Washington, D. C. hearings, and the material submitted in response to the September, 1971 EPA technology assessment survey questionnaire. The suspension applications were a prime source of material on Ford, Chrysler, General Motors, International Harvester, and Volvo. The hearing testimony provided supplementary data on these manufacturers, and, in addition, yielded information on the first-choice systems for American Motors, British Leyland, Daimler-Benz, Nissan, Saab, Toyo Kogyo, Toyota, and Volkswagen. The 1971 EPA survey provided the data base for the other auto manufacturers discussed in this section: Alfa Romeo, BMW, Citroen, Honda, Mitsubishi, Renault, and Rolls-Royce.

The 1975 emission control system is exemplified by the following package of components and engine modifications:

Oxidizing catalytic converter
Air injection
Exhaust gas recirculation (EGR)
Carburetor modifications
Ignition system modifications

With the exception of Toyo Kogyo which utilizes a thermal reactor, all of the manufacturers' first-choice systems incorporate an oxidizing catalytic converter with air injection to promote the oxidation of unburned hydrocarbons (HC) and carbon monoxide (CO) of the engine exhaust. The catalytic converter type which appears most frequently among the selected first-choice systems is the noble metal/monolithic catalyst exemplified by the Engelhard PTX design. General Motors, International Harvester, and a number of other manufacturers have selected the base metal/pelletized (AC-Delco) type of converter as a first-choice design. In many cases a firm decision as to catalyst type has not been made and several systems are being tested and evaluated concurrently.

Nearly all of the first-choice systems employ EGR for the control of oxides of nitrogen (NO_x). However, most British Leyland and the Toyo Kogyo and Saab vehicles exported to the U.S. are said to be capable of meeting the 1975 3.10 gm/mi NO_x standard without EGR.

In addition to the aftertreatment systems delineated above, a number of manufacturers, including Chrysler, GM, and Ford, utilize a partial thermal reactor in place of the conventional exhaust manifold, primarily to provide rapid warmup of the catalytic converter under cold start conditions.

Carburetion system modifications that have been identified for first choice systems range from complete redesigns, utilizing new concepts, to minor improvements to the current conventional systems. These modifications are generally directed toward improving the precision and stability of the air/fuel ratio and also include such features as altitude compensation, quick release choke devices, and induction manifold heating. All of the domestic and several of the foreign manufacturers propose, or have in development, electronic (breakerless) ignition systems which are targeted for inclusion in their first-choice system. These systems generally provide an improvement in spark-timing precision, consistency and reliability.

The most pervasive problem in the industry relative to 1975 emission control systems appears to be the lack of adequate durability in the catalytic converters currently under test. Catalyst durability is composed of two aspects: physical durability and emission durability. For monolithic designs, the physical aspect of the problem is symptomized by cracking and local melting of the catalyst substrate, due to vibratory loads and overtemperature. For pellet-type systems, the problem is exhibited as a loss of catalyst material, caused by brittleness of the pellets and/or deficiencies in the design and construction of the support grids. Physical breakdown appears to be particularly severe in 4-cylinder engine systems because of characteristically high vibrations. Canister deformation and rupture failures have occurred with both types of converter designs.

Emission durability is most strongly impacted by a loss of catalyst efficiency with accumulated mileage without mechanical deterioration. The problem has several causes, including poisoning of the catalyst due to small quantities of lead, sulfur, or phosphorous in the fuel and/or loss of catalyst surface area due to overheating. The overheating effect appears to be primarily related to rich air/fuel operation and may be encountered under various engine/vehicle operating conditions including acceleration, deceleration, choking, high-power operation, and malfunctions of different types.

In addition to the catalytic converter, durability problems with other 1975 emission system components are reported. Notable among these are EGR valves and thermal reactors.

Other problems which appear to be characteristic of 1975 emission control systems are degradation of vehicle driveability, loss of vehicle performance, and deterioration of fuel economy. Driveability problems reported encompass the following: loss of cold start driveaway capability, stumbles, stalls, inadequate acceleration, difficulty in hot starting, rough idle, surging, hesitation, and backfire. Power losses and losses in fuel economy (relative to 1972 vehicles) range from 10 to 20 percent for both parameters.

The catalytic converter durability problem is being treated in several ways. One of these is characterized by improvements in the basic design of the converter (by the catalyst supplier); another technique involves improvements in the precision control of the converter operating environment (by the auto manufacturer). Basic converter design innovations include the use of stacked (layered) and extruded monolithic substrates having superior physical properties to first-generation rolled or spiral designs, improved pellet configurations and grid systems, and better shock-mounting and support arrangements. Limit regulation of air/fuel mixtures, improved carburetion, and converter by-pass overtemperature protection systems are some of the techniques under development for controlling the quality of the exhaust flow to the catalyst.

With regard to the degradation of vehicle driveability, performance, and fuel economy, improvements are being sought by modifying the design of the fuel metering, induction, and ignition systems. Electronic engine control, which integrates the adjustment of ignition timing, air/fuel ratio, and EGR flowrate with respect to engine load and RPM, may provide the means to achieve an optimized balance of exhaust emissions versus vehicle performance and economy. Electronic engine control is a feature of the Chrysler first-choice system.

The emission performance of the 1975 systems is categorized in terms of low and high (4000^{+}) mileage accumulation. Many of the manufacturers' low mileage test results fall well within the 1975 standards; most of these systems drift outside the limits of the standards at low levels of mileage accumulation. In general, zero-mileage vehicles do not meet the manufacturers' internal engineering emission goals.

The status of high mileage emission level capabilities for 1975 first-choice systems may be gauged from the summary of best high mileage emission results presented in Table 2-1. The maximum mileage accumulated with all three pollutants within standards was 32,000 miles, achieved by an American Motors Javelin (3000-lb, 6-cylinder, 258-CID engine) equipped with an AC-Delco base metal, pelletized catalytic converter (Car D17-11). This system is continuing to accumulate mileage (EPA durability driving schedule).

Table 2-1. First-Choice Systems, Summary of Best High Mileage Emission Results

Manufacturer	Test or Car No.	First-Choice System Components	Mileage	1975 CVS-CH Emissions, gm/mi			Remarks
				HC	CO	NO_x	
American Motors	D17-11	EM + EGR + AI + OC	32,000	0.39	3.04	1.5	9, 12, Base OC
American Motors	D00-24	EM + EGR + AI + OC	50,000	(0.32	4.8	2.1)[1]	Noble OC
Chrysler	698	EM + EGR + AI + PTR + OC	43,000	(0.16	1.88	3.91)[2]	5, 8, 12, Noble OC
Ford	Ford #1	EM + EGR + AI (+ TR) + OC	8,000	0.25	1.84	2.55	9, 13, Noble OC
General Motors	2222	EM + EGR + AI + PTR + OC	8,000	0.32	4.6	2.6	9, Base OC
International Harvester	–	EM + EGR + AI + OC	4,000	0.33	4.7	–	3
Alfa Romeo	–	Not defined	–	–	–	–	6
BMW	–	EM + EGR + AI + OC	–	–	–	–	6
British Leyland	Austin	EM + AI + OC	11,400	0.28	2.73	2.32	7, Noble OC
Citroen	–	Not defined	–	–	–	–	6
Daimler-Benz	–	EM + EGR + AI + OC	–	–	–	–	6
Honda	–	Not defined	–	–	–	–	6
Mitsubishi	–	EM + AI (+ TR) + OC	10,000	0.5	3.9	–	3
Nissan	–	EM + EGR + AI + OC	8,000	0.2	1.2	0.78	14, Noble OC
Renault	R16	AI + OC	16,000	0.32	3.91	1.69	4, 10, Noble OC
Saab	–	EM + AI + OC	–	–	–	–	6, Noble OC
Toyo Kogyo	–	(EM) + AI + TR (+ OC for reciprocating)	–	–	–	–	6
Toyota	75-A	EM + EGR + AI + OC	8,000	0.27	2.82	1.29	5, 11, 14, Noble OC
Volkswagen	–	EM (+ EFI) + EGR + AI + TR + OC	–	–	–	–	6, Noble OC
Volvo	OB44085	EM + EGR + AI + OC	25,344[8]	0.24	2.45	1.82	5, 12, Noble OC

1. Least-squares fit to 1972 test results converted to 1975 test procedure; slow choke
2. 1972 CVS-C test procedure
3. No high mileage data met standards
4. Emissions package incomplete/uncertain
5. Converter subsequently failed (within 4000 miles)
6. No high mileage data provided
7. Exceeded standards below 17,000 miles
8. Converter miles
9. Test continuing
10. Average of two tests
11. After maintenance
12. Standards were exceeded at lower mileage points
13. Best of two tests
14. Non-standard maintenance schedule

AI – Air Injection
EFI – Electronic Fuel Injection
EGR – Exhaust Gas Recirculation
EM – Engine Modifications
OC – Oxidizing Catalyst
PTR – Partial Thermal Reactor
TR – Thermal Reactor

Two other high mileage vehicles may be noted. One of these is an American Motors 1970 production model Hornet (same vehicle weight and engine as the Javelin). This vehicle (Car D00-24), equipped with an Engelhard PTX 423 noble metal monolithic catalytic converter, has completed 50,000 miles of durability testing and at this mileage a least squares data fit indicates the emissions were 0.32, 4.8, and 2.1 gm/mi for HC, CO, and NO_x, respectively. The 1975 CO standard of 3.4 gm/mi was exceeded at roughly 30,000 miles. The other high mileage vehicle is a 400-CID Chrysler car. This vehicle (Car 698), equipped with dual Engelhard platinum/monolith converters which had been transferred from another vehicle, developed a total converter mileage of 43,000 miles at emission levels of 0.16, 1.88, and 3.91 gm/mi for HC, CO, and NO_x, respectively. The catalyst container failed mechanically at this point.

In addition to the two high mileage vehicles discussed above, the Volvo first-choice emission vehicle might also be mentioned. This system accumulated 25,344 converter miles within standards. The catalyst failed mechanically at 29,900 miles.

Summarizing the emissions performance indicated by the data in Table 2-1, eight first-choice systems have met the standards at accumulated mileages in excess of 4000 miles. None of these has achieved the 50,000-mile durability requirement; one system has met the standard at 32,000 miles and is still under test. A total of three systems have demonstrated the potential of achieving 25,000 converter miles within standards; two of the converters subsequently failed in test. A total of three catalytic converter failures occurred among the eight test vehicles which met the standards at more than 4000 miles.

In the main, the alternate systems under investigation by the manufacturers for potential use in 1975 model year vehicles incorporate different types or designs of catalytic converters but are otherwise similar to the emission control packages selected as first-choice systems. A typical example is

GM, whose second- and third-choice systems substitute noble metal pellet and noble metal monolithic converter designs for the first-choice base metal pellet converter design. Therefore, the discussion in the preceding paragraphs, encompassing system descriptions, problems and plans for resolution, and fuel consumption and performance penalties, applies also to most of the systems in the alternate systems category.

At least four manufacturers are experimenting with alternate 1975 emission control systems which incorporate full-size thermal reactors. These are Ford, GM, International Harvester, and Nissan.* The Ford system is installed on their Group II test fleet vehicles which are equipped with dual (series) noble metal catalytic converters, a thermal reactor, and EGR. The GM system consists of a thermal reactor with EGR. Durability data for these systems are not provided. The International Harvester system exceeds the standards at zero mileage.

The Nissan system comprises engine modifications, a thermal reactor, EGR, and an oxidizing catalytic converter. Problems encountered with the Nissan reactor may be represented as being typical of thermal reactors. These problems are reactor core deformation and durability, and the need to develop inexpensive materials which will survive the high-temperature, turbulent core environment. The fuel consumption penalty for the Nissan system was quoted as 10 to 15 percent relative to 1972 model year vehicles. The maximum mileage accumulated on this system was 32,000 miles at emission levels ranging from 0.5 to 0.75 gm/mi HC, 11 to 13 gm/mi CO, and 0.75 to 1.1 gm/mi NO_x. This system may be under development for 1976.

It may be noted that Toyota is testing a thermal reactor system which also appears to be targeted to the 1976 model year. The system incorporates engine modifications, EGR, an oxidizing catalyst, and a reducing catalyst.

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*The Toyo Kogyo thermal reactors are classified as first-choice devices.

Two vehicles equipped with this system failed the CO standard before 8000 miles were accumulated.

2.2 SELECTED SYSTEMS -- BY MANUFACTURER

2.2.1 American Motors

2.2.1.1 First-Choice System

2.2.1.1.1 Special Design Features

American Motors first-choice 1975 system includes EGR, secondary air injection, an oxidizing catalytic converter, and extensive engine modifications. A final decision has not been made as to whether the catalytic converter will be a noble metal monolithic type or a base metal pelletized type. Designs which appear to be prime candidates are the Engelhard noble metal system and the AC-Delco base metal system. The engine modifications include changes in the carburetion, induction system, valve timing, cylinder head design, ignition system, and combustion chamber configuration.

2.2.1.1.2 Problem Areas and Plans for Resolution

The problems delineated by American Motors include the following:

a. Vehicles tested to date are far from satisfactory in terms of driveability and freedom from stalling and rough operation during the first few miles after a cold start. American Motors is attempting to resolve these problems by revising the design of the fuel metering, induction, and ignition systems.

b. Emission control durability is difficult to achieve. Although American Motors has tested several vehicles to extended durability mileage, none has met their engineering goals beyond 4000 miles. This is attributed to durability deficiencies in both the catalyst and the engine (valve and ignition) systems.

c. Major underbody changes are required to permit packaging the emission control system. American Motors states that a minimum lead time of 2 years is needed to effect the necessary body changes.

2.2.1.1.3 Emissions

2.2.1.1.3.1 Test Programs and Vehicle Description

American Motors is currently testing several prototype emission control systems installed in a broad spectrum of 6- and 8-cylinder engine/vehicle combinations, both with and without EGR. The test fleet encompasses three different 6-cylinder engine sizes (199, 232, 258 CID) mounted in two different inertia weight vehicles (3000, 3500 lb), and two V-8 engines (304, 360 CID) mounted in 3500- and 4000-lb inertia weight vehicles.

2.2.1.1.3.2 Test Procedures

Durability vehicles were tested using the AMA driving cycle. Emission testing employed both the 1972 CVS-C and the 1975 CVS-CH Federal Test Procedures. All tests were conducted with fuel containing less than 0.024 gm/gal lead (0.014 gm/gal typical), less than 0.001 gm/gal phosphorous, and less than 0.04 percent by weight sulphur.

Emission levels on Vehicle D00-24 were obtained using the 1972 CVS-C test procedure throughout the 50,000-mile durability test. At 50,000 miles, this vehicle was also tested using the 1975 CVS-CH test procedure and the ratio of CVS-CH to CVS-C emission levels determined. This ratio, defined by American Motors as the correlation ratio, was then applied to the CVS-C test points over the entire 50,000 mile range to arrive at the "calculated" CVS-CH emission data presented in Figures 2-1, -2 and -3.

2.2.1.1.3.3 Emission Data Summary

Emission data reported by American Motors (Refs. 2-1 and 2-2) are presented in Tables 2-2 and 2-3 and Figures 2-1 through 2-12. The test vehicles indicated are equipped with various emission control devices including catalytic converters. With the exceptions noted in Table 2-2, all vehicles are equipped with EGR; other equipment is not delineated except as noted. None of the vehicles represents a complete 1975 prototype system.

Table 2-2. Low Mileage Emission Data -- American Motors First-Choice System

Car No.	Inertia Weight, lb	Engine	Test Mileage	Test Procedure	Emissions, gm/mi			Remarks
					HC	CO	NO_x	
D27-1	3500	360-V8	0	1975 CVS-CH	0.50	5.01	3.24	AC base metal pellet
D21-4	4000	304-V8	0	1972 CVS-C	1.02	23.10	1.49(2)	(1)
D00-12	3000	199-6	0	1972 CVS-C	0.29	6.26	2.38	(1)
D08-6	4000	360-V8	4000	1975 CVS-CH	0.39	2.50	3.20(2)	Without EGR;2 UOP miniverter
D11-2	4000	360-V8	0	1975 CVS-CH	0.39	6.09	2.83(2)	AC base metal pellet
D11-3	3500	258-6	0	1975 CVS-CH	0.23	1.47	2.12(2)	AC base metal pellet
Buck I	3500	304-V8	0	1972 CVS-C	0.30	4.73	–	(1)
D14-2	3000	232-6	0	1975 CVS-CH	0.23	2.38	3.28	Without EGR; AC base metal pellet
Buck II	3500	304-V8	0	1972-CVS-C	0.37	4.53	–	(1)
Buck III	3500	304-V8	0	1972 CVS-C	0.44	5.07	–	(1)
D20-6	3500	304-V8	0	1975 CVS-CH	0.25	2.03	1.95	(1)
Buck IV	3500	304-V8	0	1972 CVS-C	0.75	5.78	–	(1)

(1) Catalyst type and manufacturer not specified.

(2) Contradictory data, Refs. 2-3 and 2-4.

Table 2-3. High Mileage Emission Data -- American Motors First-Choice System

Car No.	Inertia Weight, lb	Engine	Test Mileage	Test Procedure	Emissions, gm/mi			Remarks
					HC	CO	NO_x	
D17-11	3000	258-6	32,000	1975 CVS-CH	0.39	3.04	1.50	AC base metal catalyst. Test continuing
D00-24	3000	232-6	50,000	1975 CVS-CH	0.45 0.32	6.46 4.80	2.05(1) 2.10(2)	Engelhard noble metal PTX-423 catalyst. Test completed
D00-25	3000	232-6	24,000	1975 CVS-CH	0.75	8.57	2.75(3)	Engelhard noble metal PTX-423 catalyst. Test terminated
D01-28	4000	360-V8	12,000	1975 CVS-CH	1.21	16.94	4.33(4)	AC base metal catalyst. Test continuing.

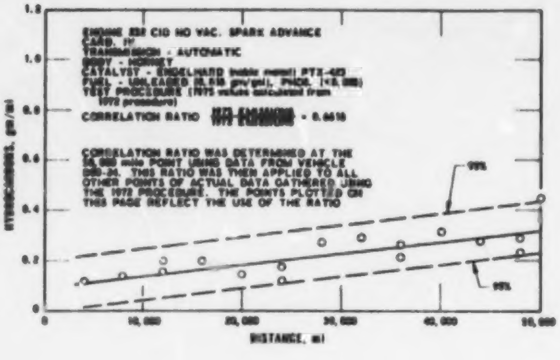
(1) Test points at 50,000 miles from Figures 2-1 through 2-3.

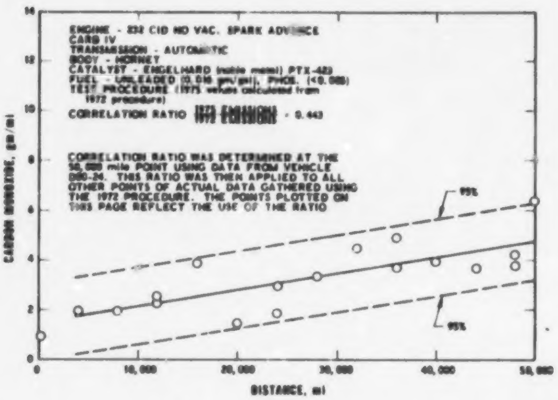
(2) Least squares straight line calculated values at 50,000 miles.

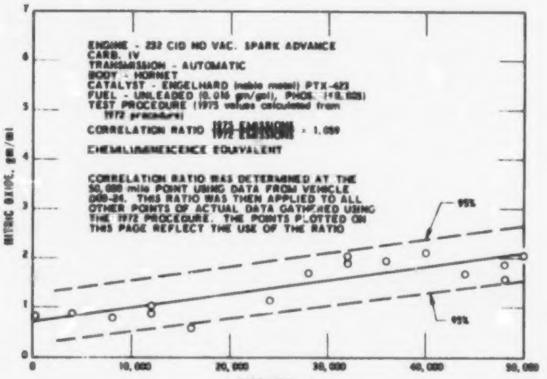
(3) Before maintenance.

(4) After maintenance.

EMISSIONS

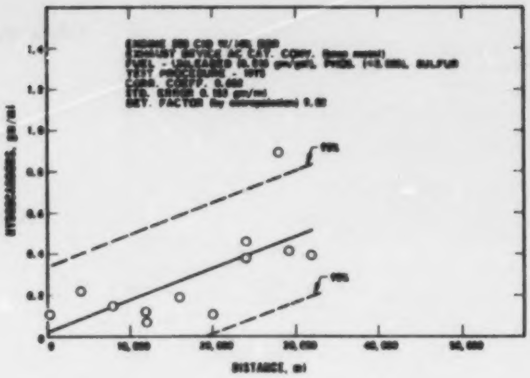




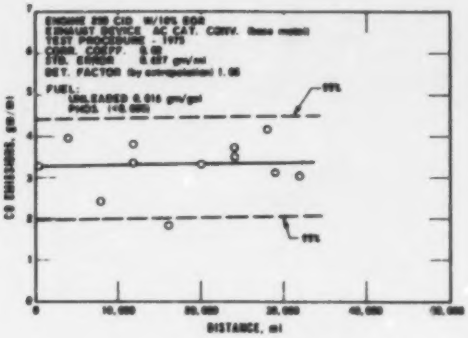


Figures 2-1, 2-2, 2-3. American Motors Durability Test Data--Vehicle D00-24

EMISSIONS



HC



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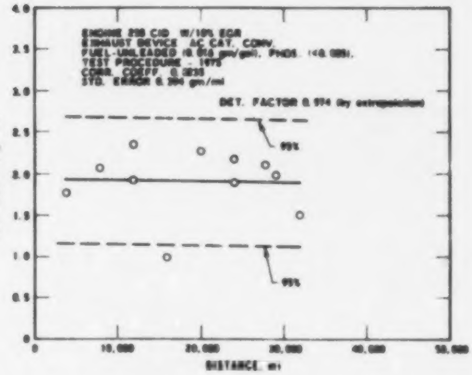
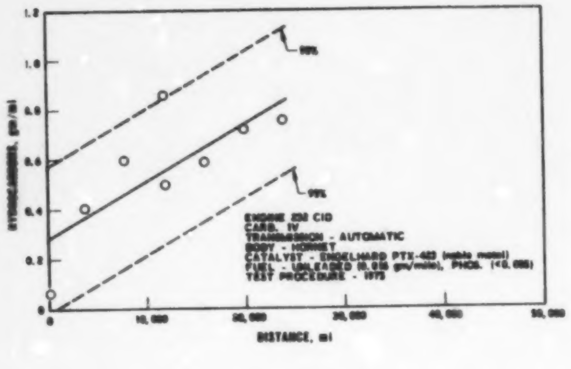


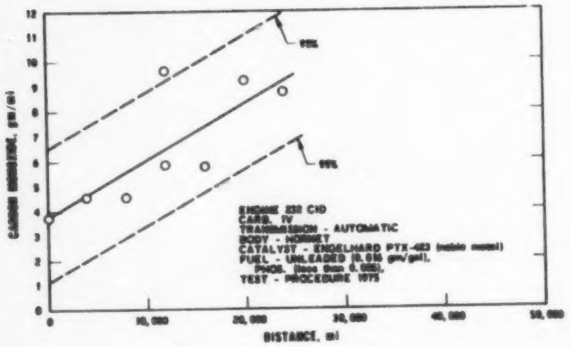
NO_x

Figures 2-4, 2-5, 2-6. American Motors Durability Test Data--Vehicle D17-11

EMISSIONS



HC



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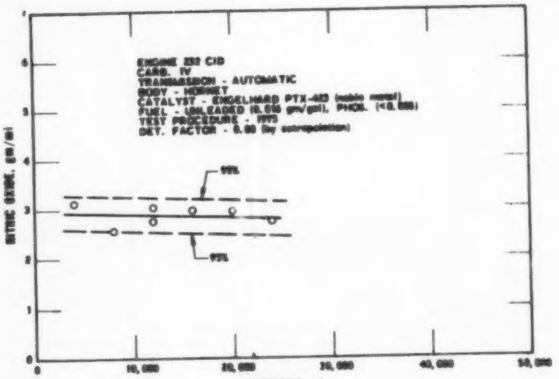
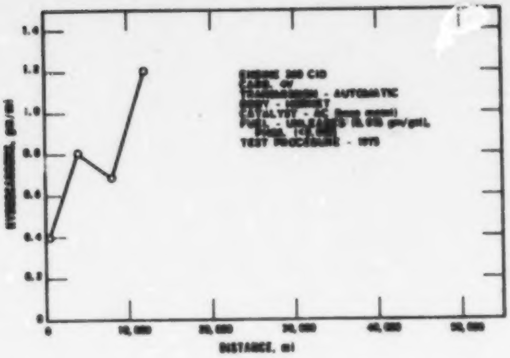


NO_x

Figures 2-7, 2-8, 2-9. American Motors Durability Test Data--Vehicle D00-25



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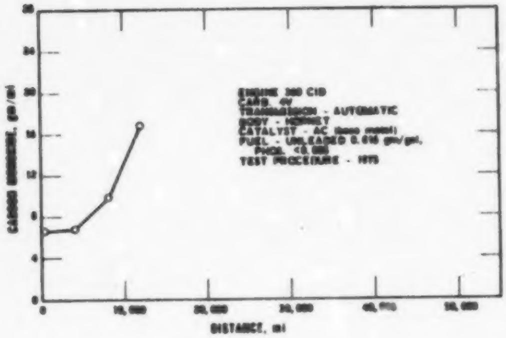
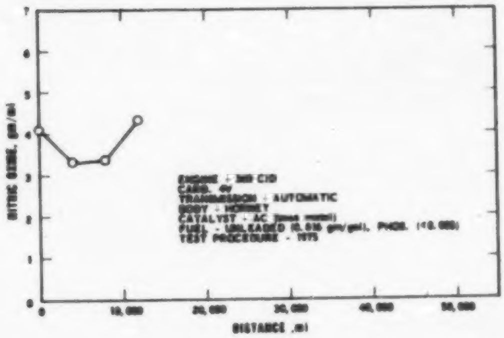


CO



NO_x

Figures 2-10, 2-11, 2-12. American Motors Durability Test Data--Vehicle D01-28R

High mileage emission data are presented in Figures 2-1 through 2-12. The data are summarized in Table 2-3 which shows emission results at the highest mileage accumulated on each vehicle.

Referring to the high mileage emission results, there are two vehicles of particular interest on the basis of performance. These are Vehicles D00-24 and D17-11. Vehicle D00-24 is a 1970 production model 258-CID 6-cylinder Hornet equipped with EGR, secondary air, and an Engelhard noble metal (PTX 423) monolithic catalytic converter. The vehicle inertia weight is 3000 lb. This vehicle has completed the 50,000-mile durability test with both the HC and NO_x emission levels below the 1975 standards based upon the least squares fit to the emission test results shown in Figures 2-1 through 2-3. The CO straight line value at 50,000 miles exceeded the standard by a factor of approximately 40 percent.

The other vehicle of interest is D17-11 which to date has accumulated 32,000 miles, with all emission levels below the 1975 standards. This vehicle is a 258-CID 6-cylinder Javelin equipped with EGR (10 percent), secondary air, and an AC-Delco base metal pelletized catalyst. The vehicle inertia weight is 3000 lb. Emission results achieved through 32,000 miles are shown in Figures 2-4 through 2-7. Durability testing of this vehicle is continuing.

Two additional vehicles are undergoing EPA durability testing at American Motors. These are vehicles D00-25 and D01-28R. Vehicle D00-25 is a 232-CID 6-cylinder Hornet equipped with EGR, secondary air, and an Engelhard PTX-423 catalytic converter. The vehicle inertia weight is 3000 lb. American Motors states (Ref. 2-3) that this test was terminated at 20,000 miles because of high deterioration rates. However, the test mileage data submitted in Ref. 2-3 indicates an additional test point at 28,000 miles as shown in Figures 2-7 through 2-9. At the 24,000 mile test point, both the HC and CO emission levels were significantly higher than the 1975 standards.

Vehicle D01-28R is a 360-CID V-8 Hornet equipped with EGR, secondary air, and an AC-Delco base metal catalytic converter. The vehicle inertia weight is 4000 lb. Emission results achieved through 12,000 miles are shown in Figures 2-10 through 2-12. Poor emission control has been exhibited on this vehicle, with CO and NO_x exceeding the 1975 standards from 0 miles and HC from 4000 miles. Extremely rapid deterioration of the catalyst efficiency is also indicated by both the HC and CO data.

2.2.1.1.3.4 Best Emission Results

The best low and high mileage emission results reported to date by American Motors (Ref. 2-4) are shown below in Table 2-4. It is of interest to note that in each case this was achieved with the 258-CID 6-cylinder engine mounted in the 3000- and 3500-lb inertia weight vehicles. Also shown in Table 2-4 are the American Motors engineering goals at 0 and 4000 miles. It will be noted that Vehicle D11-3 meets the CO and NO_x engineering goals at 0 miles but exceeds the HC goals at both 0 and 4000 miles.

Table 2-4. Best Emission Results -- American Motors

Item	Vehicle	Engine	Miles	HC	CO	NO_x
Best High Mileage	D17-11	258-6	32,000(1)	0.39	3.04	1.50
Best Low Mileage	D11-3	258-6	0	0.23	1.47	2.12
Engineering Goals						
at 0 miles				0.10	1.50	2.2
at 4000 miles				0.15	2.55	2.2

---

(1) Standards were exceeded at several mileage test points below 32,000 miles.

2.2.1.1.3.5 Test Data Variability

Test data variability as reported by American Motors (Ref. 2-4) for seven 6- and 8-cylinder low mileage vehicles has been utilized to calculate the coefficient of variation ($\sigma/\bar{x}$, %) for consecutive CVS-CH tests, where σ is the standard deviation and $\bar{x}$ the average of the test data. The range in the calculated coefficient of variation is shown in Table 2-5.

Table 2-5. Range of Test Data Variability for American Motors Low Mileage Vehicles

(Coefficient of Variation, $\sigma/\bar{x}$,%)

HC	6 - 21%
CO	11 - 21%
NO_x	1 - 10%

2.2.1.1.4 Fuel Consumption and Performance Penalties

Fuel consumption penalties associated with 1975 model year vehicles were not discussed in detail by American Motors beyond a statement estimating that the fuel consumption would increase by 8 to 18 percent over the 1972 vehicles (Ref. 2-4). Those portions of the 1975 emission control system which would contribute to this increase in fuel consumption were not discussed.

Specific reductions in performance were not presented by American Motors other than to delineate it as one of the major unresolved problem areas associated with the catalyst-EGR system being developed to meet the 1975 standards. General driveability was described as far from satisfactory (Ref. 2-4), as was freedom from stalling and rough operation during the first few miles after a cold start.

2.2.1.2 Alternate Systems

American Motors does not have an alternate 1975 system. They believe their first-choice system is the only approach which has any chance for success and that exploring alternative or second-choice systems would dilute their primary effort (Ref. 2-4).

2.2.2 Chrysler

2.2.2.1 First-Choice Systems

2.2.2.1.1 Special Design Features

Chrysler's first-choice 1975 emission control system incorporates the following devices and modifications (Ref. 2-5, -6, -7):

- Catalytic converter (platinum/monolith)
- Exhaust gas recirculation (EGR)
- Exhaust port air injection
- Catalyst by-pass protection system
- Partial exhaust thermal reactor
- Engine modifications
  - Double wall exhaust pipe
  - Heated carburetor air intake
  - Carburetor mixture calibration with barometric pressure control and electric assisted choke.
  - Electronic engine control

Chrysler's reasons for selecting this system may be summarized as follows. The selection of the catalytic converter was based on the success achieved with this device in meeting the 1975 standards under zero-mileage laboratory conditions. The monolithic noble metal converter design was preferentially selected over pelletized systems on the basis of Chrysler's experience that the noble monolith had higher activity at the lower engine temperatures. Also, Chrysler's early development work with pebble-bed catalysts showed pronounced deterioration problems. The converter utilizes a monolith ceramic substrate coated with an Engelhard platinum catalyst encased in a 304 stainless steel container. The device is positioned close to the engine in the toeboard location, based on the need for fast warmup and adequate operating temperatures as well as the availability of space.

The exhaust thermal reactor and the auxiliary air supplied to the exhaust ports is employed to burn a major portion of the combustibles in the exhaust during cold start and warmup and to increase catalyst temperature to an effective operating level. EGR is employed to provide NO_x control. Substantial development of the EGR system is proceeding to provide flow control and durability of all components involved. The double wall exhaust pipe minimizes heat loss between the thermal reactor and the catalytic converter. It thus helps in achieving a faster warmup of the catalyst to "light-off" temperature.

Chrysler states that any temperature in excess of 1500 °F can seriously damage the effectiveness of the catalyst; therefore, a by-pass protection against high exhaust gas temperatures is provided to route the exhaust gas around the converter whenever the limiting temperature is exceeded.

2.2.2.1.2 Problem Areas and Plans for Resolution

Chrysler reports that while they have made encouraging progress to date, a number of difficult problems remain to be resolved. The most pressing of these are:

Material durability at high temperature
Vehicle driveability
50,000-mile durability of system components
Maintenance of emission levels for 50,000 miles
Fuel penalties
Reducing system cost

Chrysler's goal is to optimize the system as a whole to achieve the lowest possible emission levels consistent with safe, dependable performance. The fuel penalties are brought about by vehicles made heavier by the added safety and emission control systems, decreased compression ratios, ignition spark timing changes to achieve maximum emission control, EGR which requires richer air/fuel ratios to retain acceptable and safe driveability, and by increased exhaust backpressure.

Durability of the subsystems is an area of great concern to Chrysler. Catastrophic failure of the catalyst container has occurred, produced by such events as ignition system failure under cruise conditions. A catalyst by-pass and actuator device has been under development, but its success depends on the development of a reliable sensor system. The location of the sensor is very critical since any delay can result in temporary overtemperature conditions. Low temperature switch settings can result in loss of emission control at steady-state operating conditions. Lack of suitable sensors with adequate response characteristics is delaying meaningful durability evaluations.

Although platinum monolith catalysts continue to be favored for emission effectiveness and durability, recent progress reported by catalyst manufacturers with improved pebble catalysts is prompting Chrysler to re-evaluate this type of system.

2.2.2.1.3 Emissions

2.2.2.1.3.1 Test Programs and Vehicle Descriptions

A fleet of eight 1973 Plymouth Furys are being used for development testing of the first-choice emission control system. This program has the code name A-335 and was initiated in April 1971. The eight cars are equipped with a 360 CID V-8 engine, automatic transmission, power steering and brakes, and air conditioning.

A schematic of the vehicle emissions package is provided in Figure 2-13. Supplementary information on emission system components is being obtained from research vehicles other than those in this eight vehicle test fleet. For example, Chrysler Vehicle #333 (see Table 2-6) has provided considerable information pertaining to catalyst durability. Other vehicles have been used to establish the performance of the emission control package with different engine sizes.

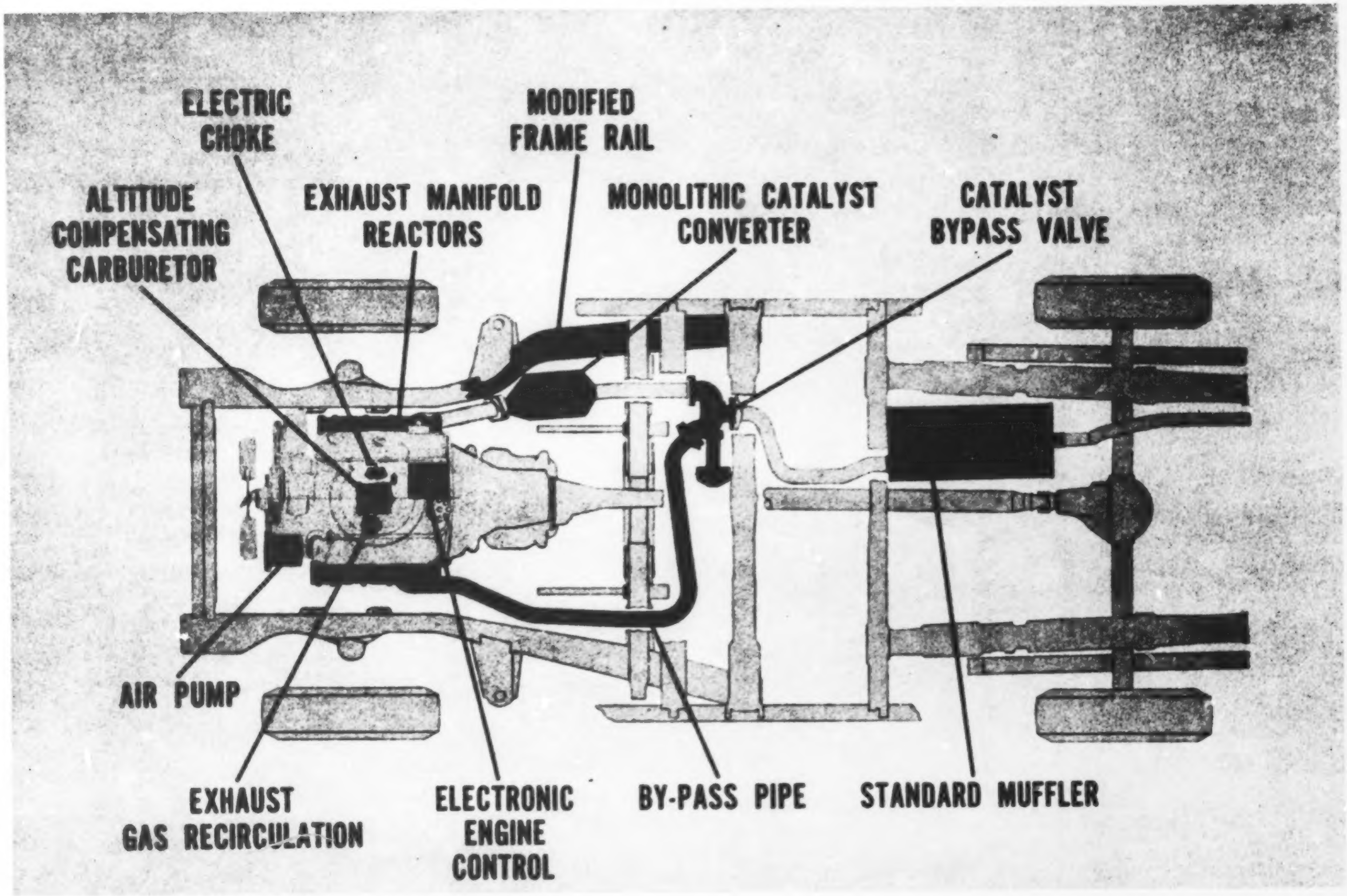

ELECTRIC CHOKE
MODIFIED FRAME RAIL
ALTITUDE COMPENSATING CARBURETOR
EXHAUST MANIFOLD REACTORS
MONOLITHIC CATALYST CONVERTER
CATALYST BYPASS VALVE
AIR PUMP
EXHAUST GAS RECIRCULATION
ELECTRONIC ENGINE CONTROL
BY-PASS PIPE
STANDARD MUFFLER

Figure 2-13. Chrysler A-335 Special Emission Car (System Features)

2.2.2.1.3.2 Test Procedures

A major portion of vehicle test work is carried out at the Chrysler Proving Ground in Chelsea, Michigan. This facility is used to test the emissions control systems under a variety of operating conditions. Also conducted at this location are the official certification activities and mileage accumulation tests. A modified AMA schedule is generally used for mileage accumulation; however, certain of the Chrysler durability vehicles were run on driving schedules which were considerably milder than the modified AMA cycle.

Chrysler has used four different emission test procedures:

1975-CVS-CH	1975 Federal Test Procedure (three bag cold/hot start technique).
1972-CVS-C	1972 Federal Test Procedure (one bag cold start technique).
1972-CVS-H	Same as 1972 CVS-C except the car does not have a cold soak and is started in a warmed up condition.
Hot 7-mode	One hot cycle of the 1971 Federal Test Procedure.

Most tests are being made with fuel containing 0.02 - 0.03 gm/gal of lead. Chrysler believes that the catalyst durability might be cut in half using the proposed Federal lead level of 0.05 gm/gal (max).

2.2.2.1.3.3 Emission Data Summary

Chrysler's emissions results are presented in Tables 2-6 and 2-7. Low mileage emission results are shown in Table 2-6. The cars listed have been used not only to test the effectiveness of the first choice subsystems but also to test the effects of such engine adjustments as spark advance and EGR flow rates. Two mileages are shown: one is representative of the accumulated mileage on the defined system, the other is the total accumulated mileage on the particular catalytic converter configuration being tested.

Table 2-6. Chrysler Low Mileage Emissions

Car No.	Engine CID	Mileage		Emissions, gm/mi			Test Procedures	Converter or Thermal Reactor (TR)	Remarks
		Vehicle	Catalyst	HC	CO	NO_x			
119	440	396	396	0.39	2.8	2.85	1975-CVS-CH	Engelhard Vert/Oval, 135 in^3 (.2% Pt). No TR	Air Pump 1.25:1
		671	671	0.26	0.7	1.51			Air Pump 1.67:1
		1038	1038	0.13	1.3	1.85			Choke mod; leaner A/F
		1268	1268	0.23	1.0	1.28			Choke mod; high-flow EGR valve
134	360	157	157	0.28	8.4	2.26	1972-CVS-C	Engelhard Toeboard, 90 in^3 (.2% Pt). No TR	Air pump 1.34:1
		183	183	0.15	3.4	2.25			EGR on at coolant above 120°
		265	265	0.22	4.9	1.66			Richer idle set
		431	431	0.29	4.3	1.54			Air pump 1.52:1
		913	913	0.20	1.5	1.78			A/F = 0.064 (richer main jet)
		987	987	0.45	9.8	2.09			A/F = 0.072
		1205	1205	0.21	7.2	1.14			New carburetor
		1489	1489	0.17	2.0	2.28			High-flow EGR valve
		1783	1783	0.40	5.9	2.24			New intake system; large Venturi 4 bbl carb.
		1969	1969	0.20	0.6	1.90	1975-CVS-CH		Larger Venturi thermo quad.
		2021	2021	0.21	0.3	1.84			
145	318	10	0	1.66	15.0	2.17	1975-CVS-CH	Engelhard Oval-Underseat. No TR	Very rich choke
		47	37	0.37	5.6	3.05			Repaired choke diaphragm
		331	321	0.29	4.7	2.42			
258	360	10	0	0.22	2.6	1.54	1972-CVS-C	Engelhard Toeboard (.35% Pt). No TR	Air pump 1.67:1
		247	237	0.39	1.4	2.92	1972-CVS-C		
		255	245	0.02	0.1	2.95	1972-CVS-H		
		332	322	1.49	5.7	4.52	1972-CVS-C		Richer idle set
		514	504	0.21	1.0	3.70	1975-CVS-CH	Thermal reactor	No EGR
		627	617	0.23	0.9	5.44			Rerunning baseline configuration

Table 2-6. Chrysler Low Mileage Emissions (Cont.)

Car No.	Engine CID	Mileage		Emissions, gm/mi			Test Procedures	Converter or Thermal Reactor (TR)	Remarks
		Vehicle	Catalyst	HC	CO	NO_x			
278	360	15	0	0.22	3.3	2.3	1972-CVS-C	Engelhard. PTR	
		112	97	0.32	5.6	1.54			Double wall exhaust pipe
		415	400	0.06	0.6	2.81			
		870	855	0.17	2.2	3.26	1975-CVS-CH		Auto spark advance control (OSAC)
		1238	1225	0.21	3.6	4.85			
		1340	1325	0.43	4.1	3.91			Standard exhaust pipe
		1446	1431	0.14	1.2	3.69			New carburetor: double wall exhaust pipe
303*	360	370	370	0.37	6.7	1.79	1972-CVS-C	Engelhard Oval (0.2% Pt). PTR	Air pump 1.34:1: cast reactors
		728	728	0.50	3.4	1.83			Tuneup, oil change
		998	998	0.12	3.9	1.55			High-flow EGR valve
		1244	1244	0.46	3.4	1.70			Carburetor and EGR valve mod
		1334	1334	0.46	14.5	1.55			Baseline plus max-flow EGR valve
306*	360	624	624	0.24	2.2	6.69	1972-CVS-C	Engelhard Oval (0.2% Pt). TR	Air pump 1.34:1; cast reactors
		1069	1069	0.38	4.3	5.31			New Carburetor
326	400-2V	143	143	0.72	6.2	4.53	1975-CVS-CH	Engelhard Vert Oval (0.2% Pt). No TR	EGR above 115° F water temp. Air pump 1.67:1
		621	621	0.52	3.1	3.63			
		819	819	0.57	4.8	2.52			Carburetor mod
		1058	1058	0.36	3.9	1.87			Tuneup and choke mod
		1201	1201	0.48	2.3	2.40			Carburetor mod
		1300**	1300**	0.30	1.2	4.00			Carburetor mod
333	360	0	0	0.41	2.48	1.49	1972-CVS-C	Twin Engelhard Toeboard (0.2% Pt). No TR	Air pump 1.7:1
		2107	2107	0.38	2.37	1.45			

Table 2-6. Chrysler Low Mileage Emissions (Cont.)

Car No.	Engine CID	Mileage		Emissions, gm/mi			Test Procedures	Converter or Thermal Reactor (TR)	Remarks
		Vehicle	Catalyst	HC	CO	NO_x			
385	360-2V	0	0	0.28	4.3	2.19	1972-CVS-C	Engelhard Toeboard (0.35% Pt). No TR	Air pump 1.526:1
		2000	2000	0.04	1.5	1.90			A/F changed
467*	360	96	96	0.08	8.0	1.50	1972-CVS-H	Engelhard Oval 135 in^3 (0.2% Pt), PTR	Air pump 1.52:1
		189	189	0.06	1.9	1.60			New carburetor
		215	215	0.24	4.3	2.10	1972-CVS-C		
467*	360	4718	0	0.34	23.9	5.04	1975-CVS-CH	New Englehard converter (0.2% Pt) 135 in^3	New engine
		4589**	171	0.12	6.5	1.43			
499*	360	107	107	0.2	3.3	2.19	1975-CVS-CH	Engelhard Horiz Oval 135 in^3 0.2% Pt). PTR	Air pump 1.52:1
585	440	0	0	0.73	2.3	2.41	1975-CVS-CH	Engelhard Toeboard Vert Oval 135 in^3 (0.2% Pt). No TR	Air pump 1.25:1
		359	359	0.16	2.6	2.07			
		3749	3749	0.30	3.7	1.69			
650	400	0	0	0.12	1.51	–	1972-CVS-H	Dual Engelhard Toeboard 107 in^3 (0.2% Pt), 2-4 containers. No TR	Air pump 1.25:1 OSAC
		1000	1000	0.14	3.65	–			
		3000	3000	0.47	2.2	1.75	Hot 7 mode		
		3000	3000	0.75	1.44	5.03	1972-CVS-H		
683	360	0	0	0.03	3.80	3.51	1972-CVS-C	Engelhard Vert Oval, 135 in^3 (0.2% Pt). No TR	Air pump 1.52:1
		3022	3022	0.05	2.50	2.93	1972-CVS-C		

*A-335 program vehicle

**Mileage estimated

Table 2-7. Chrysler High Mileage Emissions

Car No.	Engine CID	Mileage		Emissions, gm/mi			Test Procedure	Converter or Thermal Reactor (TR)	Remarks
		Vehicle	Catalyst	HC	CO	NO_x			
333	360	0	0	0.41	2.48	1.49	1972-CVS-C	Twin Engelhard Toeboard (0.2% Pt). No TR	Air pump 1.7:1
		5030	5030	0.62	5.41	1.72			Catalyst temperature kept below 1500 F
		10121	10121	0.40	4.1	1.54			
		10318	10318	0.32	2.2	1.52			EGR mods, engine tune-up
		15117	15117	0.38	3.9	2.25			
		20327	20327	1.1	11.5	2.76			
		20599	20599	0.73	5.4	2.51			New air pump
		25336	25336	0.45	6.0	3.20			
		32952	32952	0.42	5.3	2.72			
		35712	35712	0.21	4.5	1.43			Replace choke spring
		35943	35943	0.36	4.7	0.78			Replace monolith wrapping
		36094	36094	0.33	4.1	1.56			Still running
385	360-2V	0	0	0.28	4.3	2.19	1972-CVS-C	Engelhard Toeboard (0.35% Pt) (Improved catalyst, no TR)	Air pump 1.526:1
		5000	5000	0.26	6.[illegible]	1.30			
		10000	10000	0.47	2.0	1.15			
		15000	15000	0.28	2.88	1.55			
		20000	20000	0.26	2.84	1.56			Catalyst container failed at 23,000 mi.
585	440	257	257	0.20	2.4	2.46	1975-CVS-CH	Engelhard Toeboard Vert Oval 135 in^3 (0.2% Pt). No TR	Air pump 1.52:1
		3749	3749	0.30	3.7	1.69			General endurance test
		8462	8462	0.35	2.6	1.55			
		13678	13678	0.44	2.1	1.5			
		18330	18330	0.39	1.9	1.10			
		21443	21443	-	-	-			Catalyst failed
650	400	3000	3000	0.75	1.44	5.03	1972-CVS-H	Dual Engelhard PTX-423S 107 in^3 Toeboard. No TR	Air pump 1.25:1
		8000	8000	0.04	12.7	4.73			
698		0	13000	0.11	3.9	1.84	1972-CVS-C	Dual Engelhard PTX-423S 107 in^3 Toeboard. No TR	System transferred from Car 650; General endurance test; no Pb, no P in fuel
		10000	23000	0.39	1.7	2.55			
		20000	33000	0.53	2.19	4.30			
		25000	38000	0.22	3.99	3.99			New engine
		30000	43000	0.16	1.88	3.91			Converter damaged
683	360	0	0	0.03	3.80	3.81	1972-CVS-C	Engelhard Vert Oval 135 in^3 (0.2% Pt). No TR	Air pump 1.52:1
		3022	3022	0.05	2.5	2.93			General endurance test
		8350	8350	0.11	6.74	3.07			
		13284	13284	0.07	4.25	2.69			Still running

Reported high mileage emissions are listed in Table 2-7. Good emission results were obtained with Vehicle 333 using a twin configuration Engelhard converter (0.2 percent platinum on a spiral monolith substrate) in a toeboard location. Vehicle 333 was driven on an AMA schedule modified so that the catalyst temperature never exceeded 1500 ^{o}F. This car was frequently tuned up and parts replaced.

Vehicle 385 had an improved catalyst with higher platinum loading. However it was driven on the Chrysler proving ground (a more severe test than that above) and received only the customer-specified servicing. This catalyst failed at 20,000 miles. The failure was caused by abrasion of the catalyst container on the roadway. A similar test will be conducted in the near future using a stacked monolith substrate.

2.2.2.1.3.4 Best Emission Results

Several of the tests showed emission levels within the 1975 standards. Three first-choice-type systems have met the standards at high mileage.

The best low mileage emission results were obtained with Vehicle 119 (Model HP85, 440-CID engine with automatic transmission). A 135 in^3 Engelhard vertical oval converter was used. Emissions at 1268 miles were 0.23, 1.0, and 1.28 gm/mi HC, CO, and NO_x, respectively.

The best high mileage emission results were obtained with Vehicle 385 (360-2V engine with automatic transmission). This car was driven on the regular Chrysler proving ground and did not receive special servicing. The converter was an Engelhard 0.35 percent platinum monolith in a toeboard location. At 20,000 miles, the emission levels were well within 1975 standards at 0.26, 2.84 and 1.56 gm/mi HC, CO, and NO_x, respectively. However the catalyst container failed at 23,000 miles.

Two systems have done well in Chrysler's durability testing. One of these, Vehicle 333 (Plymouth Fury, 360 CID) utilized a converter designated by Chrysler as "twin Engelhard toeboard converters" (0.2 percent platinum/monolith). Mileage accumulation was accomplished using the AMA driving cycle modified to lower acceleration rates above 50 mph to hold the catalyst bed temperature below 1500 °F. The car was tuned up every 5000 miles. At 36,094 miles the emission levels per the 1972-CVS-C procedure were 0.33, 4.1, 1.56 gm/mi for HC, CO, and NO_x, respectively. At this point it was noted that the monolith was loose in its container and was abrading. The other system that performed well was run on Vehicles 650 and 698 (400 CID engine) and utilized a converter designated by Chrysler as a "dual Engelhard toeboard 107 in^3 converter" (0.2 percent platinum/monolith). This system accumulated 43,000 miles before a hole was burned in the side of one of the containers. Per the 1972-CVS-C procedure, the emissions were 0.16, 1.88, 3.91 gm/mi for HC, CO, and NO_x, respectively.

2.2.2.1.3.5 Test Data Variability

Chrysler reports that identical repeated 1975 CVS-CH tests within the same laboratory produce results that vary by about plus or minus 25 percent. Between laboratories, the variation is well over plus or minus 50 percent. Calculations made on a limited sample of data taken from Vehicle 333 show that three repeated tests in the same facility produce the following standard deviations (in percent):

$$HC = \pm 28.8, \; CO = \pm 48.6, \; NO_x = \pm 12.3$$

2.2.2.1.4 Fuel Consumption and Performance Penalties

Chrysler reports that, depending on the speed, the 1975 first-choice system would have a fuel economy of 1 to 4 mi/gal less than the 1971 system. It is also reported that in city traffic the fuel economy for the 1975 model will be 81 percent of 1968 model year values.

Chrysler states that to avoid stumbles, stalls, and inadequate acceleration, engines with larger displacement, richer air/fuel ratios, and faster idling speeds will have to be used. It is probable that the smaller engines in some models will have to be discontinued in order to retain acceptable and safe driveability. The expected performance penalty is not explicitly stated in Chrysler's submittal.

2.2.2.2 Alternate Systems

2.2.2.2.1 Special Design Features

Several modifications to the Chrysler first-choice system are being pursued. As of April 20, 1972 the final selection of the catalyst to be used in production had not been made; a number of different catalytic converter systems are currently being evaluated for possible use. The second-choice system seems to center around the use of a pellet-type converter such as the UOP stabilized spherical platinum (PTAS) catalyst. Other possible modifications to the first-choice system include (1) deletion of the 30 percent thermal reactor and of the double wall exhaust pipe (provided that cold start emissions can be brought within manageable limits), and (2) elimination of the catalyst by-pass system (provided that better exhaust gas temperature control is achieved or more tolerant catalysts are found).

2.2.2.2.2 Problem Areas and Plans for Resolution

In the past, unacceptable deterioration observed in testing pebble catalytic converters led to a decision by Chrysler to shelve these devices in favor of the noble metal monolith catalytic converter. However, recently reported advances in the technology has prompted Chrysler to re-examine the whole class of pebble-type catalysts. Chrysler plans to resume testing of the pellet systems using the performance achieved with the Engelhard PTX platinum/monolith converter as a reference for comparison. It is believed that the high temperature stability of catalysts such as UOP PX-4 might provide the basis for eliminating the 30 percent thermal reactor and the catalyst by-pass from the list of subsystems to be used on the 1975 model.

2.2.2.2.3 Emissions

The more advanced pebble-bed catalysts such as the UOP-PTAS type have not yet been tested. Emission levels obtained with some of the early pellet-type catalysts tested by Chrysler are shown in Table 2-8.

Table 2-8. Chrysler Low Mileage Emissions (Alternate Catalytic Converter Design)

Car No.	Engine CID	Mileage	Emissions, gm/mi			Test Procedure	Converter or Thermal Reactor (TR)	Remarks
			HC	CO	NO_x			
258	360	0	0.66	4.1	5.93	1975-CVS-CH	Davex 45-V toeboard pebble bed, PTR	-
		141	0.66	4.8	5.29			
259	360	0	0.30	4.5	1.39	1972-CVS-C	Monsanto ECA 302 pebble bed, PTR	
		27	0.34	3.5	1.34			
259	360	0	0.04	0.9	1.15	1972-CVS-C	Davex 137 pebble bed, PTR	
		50	0.25	5.6	2.06			
259	360	0	0.23	3.6	1.21	1972-CVS-C	Houdry 1057 JX8-2X1 pebble bed, PTR	
		170	0.17	3.6	1.83			
		496	0.40	3.1	1.41			Secondary air mod
		519	0.47	2.9	1.33			Air pump 1.52:1
		857	1.62	39.4	0.41	1975-CVS-CH		New air pump; A/F change

2.2.3 Ford

2.2.3.1 First-Choice Systems

2.2.3.1.1 Special Design Features

Based upon currently available data, it is Ford's judgment that its first-choice system for 1975 will consist of a single catalytic converter in conjunction with EGR, secondary air injection, and engine modifications. A single Engelhard PTX noble metal monolithic catalyst will be used on the 4-cylinder and 6-cylinder passenger cars and the V-8 F-100 pickup truck. Two catalysts, one on either side, will be used on the V-8 engine passenger cars.

This system is favored because the projected 50,000-mile emission performance levels closely approximate the catalyst-thermal reactor system at a substantially lower cost to the consumer. This projected cost differential to the customer has been estimated by Ford to be $140 (Ref. 2-8).

2.2.3.1.2 Problem Areas and Plans for Resolution

A major problem area reported by Ford (Ref. 2-9) is the deterioration of catalyst efficiency. No car that Ford has tested has successfully accumulated 50,000 miles and maintained the emission levels within the 1975 standards. A 32-car test program was started in March 1972 at Riverside as part of the effort to evaluate the performance of the catalyst and the emission control system as a whole.

2.2.3.1.3 Emissions

2.2.3.1.3.1 Test Programs and Vehicle Description

The current Ford test program is a two-phase program utilizing 44 vehicles: 32 vehicles are being tested at Riverside, California and 12 vehicles at Dearborn, Michigan. Phase I is a 50,000-mile durability study to determine the system/component deterioration factors. Phase II is being conducted to determine 4,000-mile emission levels which, in conjunction with the deterioration factors determined from Phase I, can be used to project certification emission capabilities of the candidate systems.

Four groups of vehicles will be tested in Phase I at Riverside. Each group of vehicles will consist of:

Two 460-CID Lincolns
Two 351C-CID Galaxies
Two 250-CID Mavericks (6 cylinder)
Two 360-CID F-100 pickup trucks

The Phase II tests to be conducted at Dearborn will consist of three of each of the above vehicles.

Current production 1972 vehicles will be modified for the Phase I and II test programs to include the appropriate exhaust system, heat shields, etc., for use with reactor manifolds and/or catalytic converters and will be equipped as follows:

Secondary air injection
Induction-hardened valve seats
Breakerless ignition
Advanced carburetors and distributors
Exhaust gas recirculation

Group I vehicles will be fitted with a single PTX noble metal monolithic catalyst on the 6-cylinder Mavericks and the F-100 pickup trucks. Two PTX monolithic catalysts will be fitted, one on each side, to the Galaxies and Lincolns. Group II vehicles will have a manifold reactor plus a second single PTX catalyst in series with the converter configuration used on Group I vehicles. Group III vehicles will consist of the dual (series) catalytic converters without the thermal reactors. A decision on the components to be used on Group IV vehicles is scheduled for late April 1972 and will be based on an analysis of the results from Groups I through III to that date.

2.2.3.1.3.2 Test Procedures

The vehicles at Riverside are being tested in accordance with the AMA durability cycle. Emission test results are based on the 1975 CVS-CH test procedure. In addition to the Riverside data, low mileage emission results (CVS-CH) were also reported for a Mercury Marquis equipped with the catalyst-only system. The driving cycle and vehicle mileage were not specified for the Mercury.

2.2.3.1.3.3 Emission Data Summary

The low mileage emission data reported by Ford for the catalyst-only equipped vehicles for both the Riverside and Dearborn fleets are presented in Table 2-9. The data shown for the Riverside vehicles are the average of two consecutive tests for each vehicle at each of the reported mileage points. It should be noted that of the Riverside vehicles, the Mavericks exceeded the 1975 standards for HC and NO_x at 2000-4000 miles, and the Lincolns exceeded the 1975 standard for HC at 0 miles and that for CO at 2,000 miles. The F-100 exceeded the 1975 standards for HC and CO at 0 miles but the data indicate a gradual reduction in HC and CO and at 4,000 miles the standards are met. The reasons for this were not clear to Ford (Ref. 2-9), but may be a "green" engine effect.

The Dearborn Test Fleet data, also shown in Table 2-9, include the results of two consecutive tests at each test mileage for each vehicle. The Dearborn cars were reported as being equipped with catalysts similar to the Group I vehicles at Riverside. Ford also reported (Ref. 2-10) that the Dearborn vehicles "have higher CO levels than the durability cars running at Riverside because of an effort to reduce NO_x emissions to levels somewhat more typical of what would be required for a 1975 model." No additional information was provided by Ford, although the fact that, in general, the Dearborn cars exhibit lower NO_x and higher HC/CO emissions than the Riverside fleet would suggest that a lower air/fuel ratio setting and/or a higher EGR rate was used on the Dearborn fleet.

Table 2-9. Low Mileage Emission Results--Ford (Group I) First-Choice System

Vehicle	Engine CID	Mileage	Emissions, gm/mi*		
			HC	CO	NO_x
Riverside Test Fleet**					
Maverick #1	250	0	0.41	2.23	2.45
		2000	0.58	3.28	2.96
		4000	0.63	3.56	3.48
Maverick #2	250	0	0.32	0.95	2.92
		2000	0.35	1.37	4.20
		4000	0.42	3.19	3.04
Ford #1	351	0	0.19	1.91	2.34
		2000	0.43	3.17	2.47
		4000	0.25	1.91	2.56
Ford #2	351	0	0.20	1.75	2.46
		2000	0.22	2.32	2.75
		4000	0.32	2.29	2.89
F-100 #1	360	0	0.55	4.42	2.30
		2000	0.47	3.82	2.55
		4000	0.38	4.40	2.47
F-100 #2	360	0	0.49	2.83	2.45
		2000	0.36	2.41	2.81
		4000	0.33	2.11	2.74
Lincoln #1	460	0	0.63	3.21	2.36
		2000	0.54	3.52	2.25
		4000	0.60	3.21	2.35
Lincoln #2	460	0	0.43	2.88	2.16
		2000	0.54	3.39	2.31
		4000	0.70	4.43	2.51
Development Vehicle					
Mercury	429	***	0.23	1.03	1.14

*CVS-CH test procedure

**Average of two consecutive tests at each mileage point

***Reported only as "low mileage"

Table 2-9. Low Mileage Emission Results--Ford (Group I) First-Choice System (continued)

Vehicle	Engine CID	Mileage	Emissions, gm/mi*		
			HC	CO	NO_x
Dearborn Test Fleet**					
Maverick	250	0	0.52	6.56	1.51
			0.29	5.69	1.54
		4000	0.54	5.68	1.76
			0.72	7.05	2.10
Ford	351	0	0.22	2.31	1.86
			0.25	3.18	1.88
		4000	0.35	5.77	1.81
			0.38	6.44	2.00
F-100	360	0	0.29	0.83	2.54
			0.20	1.44	2.37
Lincoln	460	0	0.23	2.53	1.69
			0.56	7.04	1.52
		4000	0.38	3.72	1.75
			0.31	2.46	1.72

*CVS-CH test procedure

**Equipped with catalyst similar to Group I at Riverside. These vehicles have higher CO levels than the durability cars running at Riverside because of an effort to reduce NO_x to levels somewhat more typical of what would be required for a 1975 model.

Only limited high mileage emission data are available from the Ford first-choice system being tested at Riverside. These results are presented in Table 2-10. It should be noted that the two Fords and the F-100 #2 are the only Group I vehicles which continue to meet the 1975 standards at 8000 miles.

2.2.3.1.3.4 Best Emission Results

The best low mileage emission results (average of two tests), reported by Ford for their first-choice test vehicles are presented in the table below. All results are at zero or low mileage with the exception of the F-100 pickup truck. For this vehicle, the best results were obtained at 4,000 miles.

Best Emission Results -- Ford First-Choice System

Vehicle	Miles	HC	CO	NO_x
Maverick #2	0	0.32	0.95	2.92
Ford #2	0	0.20	1.75	2.46
F-100 #2	4,000	0.33	2.11	2.74
Lincoln #2	0	0.43	2.88	2.16
Mercury	*	0.23	1.03	1.14

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*Reported only as "low mileage."

The best high mileage emission results achieved on a single test on the Ford first-choice system were obtained on the Ford Galaxie #1 being tested at Riverside. These results, at 8,000 miles, were 0.25, 1.84, and 2.55 gm/mi for HC, CO, and NO_x, respectively.

2.2.3.1.3.5 Test Data Variability

Test data variability at the 1975-76 emission levels has been reported by Ford (Ref. 2-8) in terms of the coefficient of variation, $\sigma/\bar{x}\%$, for test-to-test variability, as follows:

Table 2-10. High Mileage Emission Results--Ford First-Choice System (Riverside Test Fleet)

Vehicle	Eng. CID	Mileage	Emissions, gm/mi* HC	CO	NO_x	Remarks
Maverick #1	250	8000	0.78	2.28	3.37	
			0.66	2.37	3.46	
Maverick #2	250	8000	0.56	3.85	3.29	1 test only
Ford #1	351	8000	0.25	1.84	2.55	
			0.23	2.32	2.45	
Ford #2	351	8000	0.24	2.45	2.45	
			0.28	2.26	2.85	
F-100 #1	360	8000	0.45	5.37	2.48	1 test only
F-100 #2	360	8000	0.31	2.12	2.42	1 test only
Lincoln #1	460	8000	0.37	4.12	2.74	1 test only
Lincoln #2	460	8000	0.57	3.63	2.40	
			0.59	4.34	3.15	

*CVS-CH test procedure

Ford Test Data Variability
(Coefficient of Variation, $\sigma/\bar{x}$, %)

Emission	Test-to-Test
HC	20 - 26%
CO	19 - 34%
NO_x	10 - 23%

Although the small sample size of the data available from the Phase I durability tests on a given vehicle does not permit an accurate determination of the coefficient of variation, evaluation of the spread in the Riverside data indicates that the results to date are consistent with the test-to-test variability reported by Ford.

2.2.3.2 Alternate Systems

2.2.3.2.1 Special Design Features

Two alternate emission control systems are currently being tested by Ford at Riverside and Dearborn. These are the Group II (dual catalysts plus thermal reactor) and the Group III (dual catalysts only) vehicles described in detail in Section 2.2.3.1.3.1. A third system, designated Group IV, will also be tested following a decision on the components to be used based on the results obtained from the Group I, II and III vehicles.

2.2.3.2.2 Problem Areas and Plans for Resolution

As previously stated, Ford's primary problem concerns the durability of the emission control system. Accordingly, the Group II, III and IV vehicles are also being evaluated on the AMA durability driving cycle to determine the best combination of emission system components required to meet the 1975 emission standards over the 50,000-mile range.

Ford indicates that they plan to continue the investigation of the catalyst plus thermal reactor system vehicles as well as the thermal reactor-only system. However, a project recently completed by the Ford Car Research Office implies that a basic incompatibility may exist between reactor manifolds and catalytic converters. Material deposits were found in the catalyst which were thought to originate from the stainless steel liner of the reactor manifold. Ford speculates that these deposits may contribute to the overall deterioration of the combined system, thus causing it to deteriorate more rapidly than the catalyst-only system. Investigations attempting to resolve this issue are continuing.

2.2.3.2.3 Emissions

2.2.3.2.3.1 Test Programs and Vehicle Descriptions

AMA durability tests are being conducted at Riverside on Group II and III cars. Similar durability tests will begin in the near future on Group IV cars as part of the Ford Phase I program. Phase II (see Section 2.2.3.1.3.1) emission testing is being done concurrently at Dearborn.

2.2.3.2.3.2 Test Procedures

All emission data is being obtained in accordance with the 1975 CVS-CH test procedure.

2.2.3.2.3.3 Emission Data Summary

Low mileage emission results for the Ford dual catalyst plus thermal reactor system being tested on the Group II vehicles at Riverside and Dearborn are shown in Table 2-11. It will be noted that only a few of the Riverside Group II vehicles met the 1975 standards. These included the Maverick #1 through 2000 miles, Ford #1 at 2000 miles only, the F-100 #2 at 4000 miles only, and the Lincoln #1 at 0 miles only. Of the Dearborn cars, only the F-100 pickup truck met the standards at 0 and 4000 miles.

Table 2-11. Low Mileage Emission Data--Ford Alternate System (Group II)

Vehicle	Engine CID	Mileage	Emission, gm/mi*			Remarks
			HC	CO	NO_x	
Riverside Test Fleet**						
Maverick #1	250	0	0.22	3.23	1.76	
		2000	0.32	2.98	2.02	
		4000	0.52	5.06	1.86	1 test only
Maverick #2	250	0	0.54	8.74	1.68	
		2000	0.44	5.53	1.81	
Ford #1	351	0	0.36	3.72	2.17	
		2000	0.27	2.93	2.06	
		4000	0.40	4.82	2.08	
Ford #2	351	0	0.32	4.21	1.76	
		2000	0.40	4.65	1.88	
		4000	0.32	5.58	1.57	
F-100 #1	360	0	0.38	4.45	1.44	
		2000	0.39	4.99	1.62	
		4000	0.40	5.63	1.75	
F-100 #2	360	0	0.24	3.96	3.12	
		2000	0.25	3.43	2.55	
		4000	0.26	3.16	1.91	
Lincoln #1	460	0	0.23	2.22	2.33	
		2000	0.27	4.29	2.63	
		4000	0.26	3.58	2.33	
Lincoln #2	460	0	0.32	4.51	1.97	
		2000	0.35	6.28	2.02	
		4000	0.37	5.60	2.17	

*CVS-CH test procedure

**Average of two consecutive tests at each mileage point unless otherwise indicated.

Table 2-11. Low Mileage Emission Data--Ford Alternate System (Group II) (Cont.)

Vehicle	Engine CID	Mileage	Emission, gm/mi*			Remarks
			HC	CO	NO_x	
Dearborn Test Fleet**						
Maverick	250	0	0.49	2.59	1.55	1 test only
		4000	0.48	3.31	1.94	
			0.43	2.90	1.95	
Ford	351	0	0.28	3.98	2.15	
			0.39	4.74	2.21	
		4000	0.33	5.85	2.33	
			0.22	4.44	1.95	
F-100	360	0	0.16	0.72	1.81	
			0.10	0.68	1.40	
		4000	0.23	0.92	2.14	1 test only
Lincoln	460	0	0.21	2.04	1.72	
			0.57	7.00	1.59	
		4000	0.19	1.49	1.60	
			0.23	4.44	1.43	

*CVS-CH test procedure

**Equipped with thermal reactor and extra catalyst similar to Group III at Riverside. These vehicles have higher CO levels than the durability cars at Riverside because of an effort to reduce NO_x to levels somewhat more typical of what would be required for a 1975 model.

The primary problem with the Group II vehicles appears to be a general inability to meet the CO standard of 3.4 gm/mi.

Low mileage emission results reported to date for the Ford dual catalyst-only system, undergoing test at Riverside and Dearborn on the Group III vehicles, are shown in Table 2-12. All of the Riverside Group III vehicles met the 1975 standards at 0 miles with the exception of the Lincoln #2. However, only the Fords and F-100 pickup trucks continued to meet the standards at 2000-4000 miles. None of the Dearborn Fleet Vehicles met the standards at either 0 or 4000 miles.

No high mileage emission data have been reported for the Ford Group II and III cars undergoing durability testing at Riverside. Approximately 12,000 miles have been accumulated on a Maverick/Comet 302 CID V-8 with an emission control system similar to the Riverside Group III cars; i.e., dual catalysts in series without a thermal reactor. Results are shown in Table 2-13. It will be noted that although this vehicle continued to meet the NO_x standard over the mileage tested, HC and CO emission control deteriorated between the 3129-mile and 5803-mile test points; thereafter, the HC emissions exceeded the 1975 standards.

Two of Ford's earlier high mileage test programs that are obliquely related to the current durability evaluation may be mentioned. One of these, designated as the 1975 Durability Test Program, involved the test of six development "Concept Emission System" vehicles equipped with thermal reactor, catalytic converter, EGR, secondary air injection, and quick release choke. These vehicles were tested over the AMA durability driving cycle; emission results were obtained in accordance with the 1972 CVS-C test procedure.

Although these vehicles were tested up to 50,000 miles, this mileage value does not represent the accumulated emission system mileage since numerous system component failures occurred and replacements were made during the course of the test. A representative set of failure incidents is given by the

Table 2-12. Low Mileage Emissions--Ford Alternate System (Group III)

Vehicle	Engine CID	Mileage	Emissions, gm/mi[*]		
			HC	CO	NO_x
Riverside Test Fleet[**]					
Maverick #1	250	0	0.32	0.60	2.34
		2000	0.31	1.11	3.09
		4000	0.37	0.95	3.36
Maverick #2	250	0	0.21	1.73	2.08
		2000	0.60	2.18	2.70
Ford #1	351	0	0.17	1.77	2.26
		2000	0.20	1.51	2.20
		4000	0.28	1.56	2.45
Ford #2	351	0	0.26	1.53	2.19
		2000	0.34	1.46	2.26
F-100 #1	360	0	0.34	4.71	2.05
		2000	0.40	4.01	1.98
F-100 #2	360	0	0.32	1.71	2.09
		2000	0.44	1.23	1.95
		4000	0.34	2.22	2.35
Lincoln #1	460	0	0.28	1.59	2.10
		2000	0.31	3.55	2.59
Lincoln #2	460	0	0.24	4.26	2.18
		2000	0.31	5.68	1.99

[*] CVS-CH test procedure

[**] Average of two consecutive tests at each mileage point

Table 2-12. Low Mileage Emissions--Ford Alternate System (Group III) (continued)

Vehicle	Engine CID	Mileage	Emissions, gm/mi[*]		
			HC	CO	NO_x
Dearborn Test Fleet[**]					
Maverick	250	0	0.49	10.2	1.70
			0.56	11.2	2.12
		4000	0.62	14.5	2.32
			0.58	12.9	1.69
Ford	250	0	0.31	4.61	1.81
			0.35	6.00	1.87
		4000	0.28	6.81	1.17
			0.28	3.92	1.86
F-100	360	0	0.25	0.67	2.46
			0.40	3.78	1.63
		4000	0.44	5.90	1.46
			0.66	5.24	1.70
Lincoln	460	0	0.62	9.44	0.94
			0.69	11.70	1.01
		4000	0.99	17.43	0.89
			1.06	15.99	0.99

[*] CVS-CH test procedure

[**] Equipped with extra catalyst similar to Group III at Riverside. These vehicles have higher CO levels than durability cars running at Riverside because of an effort to reduce NO_x to levels somewhat more typical of what would be required for a 1975 model.

Table 2-13. High Mileage Emission Data--Ford Alternate System (Group III Type)

Vehicle	Miles	Emissions, gm/mi			Remarks
		HC	CO	NO_x	
Maverick/Comet	103	0.22	0.97	2.62	
302 CID	128	0.20	1.29	1.51	EGR Increased
	207	0.26	3.07	1.52	
	220	0.26	1.45	1.69	
	844	0.37	4.18	1.59	
	870	0.31	2.39	1.69	
	3035	0.35	3.07	1.67	Change power valves from 5.5 to 3.0 in Hg
	3114	0.53	2.57	1.71	
	3129	0.35	1.90	1.72	
	5803	0.62	3.32	2.12	Timing at 3° BTC. Change oil & filter
	5821	0.56	2.94	1.92	Set timing back to 6° BTC
	5888	0.88	5.43	2.39	
	5928	0.63	3.07	2.22	
	5952	0.73	5.01	1.94	
	12060	0.76	4.71	1.61	
	12088	0.80	4.51	1.96	
	12108	0.59	2.84	2.20	

test history for vehicle 12A90, a 1971 351-CID Ford. Emission system components and component failures or malfunctions for this test vehicle are described in Table 2-14; test emission results for HC and CO are shown in Figure 2-14. (NO_x levels were below the 1975 standard throughout the test.)

The other earlier high mileage test program involved a developmental fleet of five durability vehicles. The test program was started in mid-1971 to evaluate the possibility of meeting the 1974 California standards using a catalyst-only system (without thermal reactor) in conjunction with EGR, secondary air injection, and a quick-release choke. The use of this system for the 1974 model year was abandoned when it was established that lead-free fuel would not be available.

Basically, this fleet represents a developmental predecessor of the Group I vehicles currently undergoing test at Riverside and Dearborn. Approximately 50,000 miles were accumulated on each vehicle over the AMA durability test route. Emission results were obtained in accordance with the 1972 CVS-C test procedure.

Durability testing of the 1974 California model year vehicle resulted in numerous failures of emission components including catalytic converters, overtemperature controls, EGR components, air injection system components, carburetion, ignition, and engine components. Repairs and/or replacements were made as required during the course of each test and, as a result, the total vehicle durability miles do not represent emission control system durability mileage.

Typical results obtained during this test are shown for Vehicle 1A97, a 1971 400-CID Ford, in Figure 2-15 (HC and CO) and Figure 2-16 (NO_x). The HC and CO emission levels exceeded the 1975 standards while that of NO_x remained well below the standard throughout the test. Emission system components and component failures or malfunctions for this test vehicle are described in Table 2-15.

Table 2-14. Durability Test Vehicle Specifications (Vehicle No. 12A90-D)

Type: 1971 400-2V A/T Ford
Test Program: 1975 AMA Durability

Emission System Components

- Reactor cylinder heads with exhaust port liners
- Phase III spacer EGR, pickup before muffler and through cooler, cold lockout (125°F PVS)
- 19 in^3 air pump with 1.5:1 drive ratio. Replaced 1.7:1 drive ratio
- 70F57 S.D. distributor @ 6° BTC initial with cold lockout of part throttle advance (125°F PVS)
- 2100 2V GPD carburetor with ACE 39 calibration and 20 sec Schmelzer quick choke and 5 sec. restrictor
- Phase I type "H" reactors with core
- Monolithic PTX 5.35 converters

Emission Component Failures or Malfunctions During Durability

- 30,000 Miles - Converters failed; installed new PTX 5.35 converter
  - Air pump ratio changed from 1.7:1 to 1.5:1
- 35,000 Miles - Air pump failed; installed new pump
  - Transmission failed; installed new transmission
- Various mileages - Left hand reactor outlet gasket failed 9 times during durability causing engine mount failure at 26,500 miles

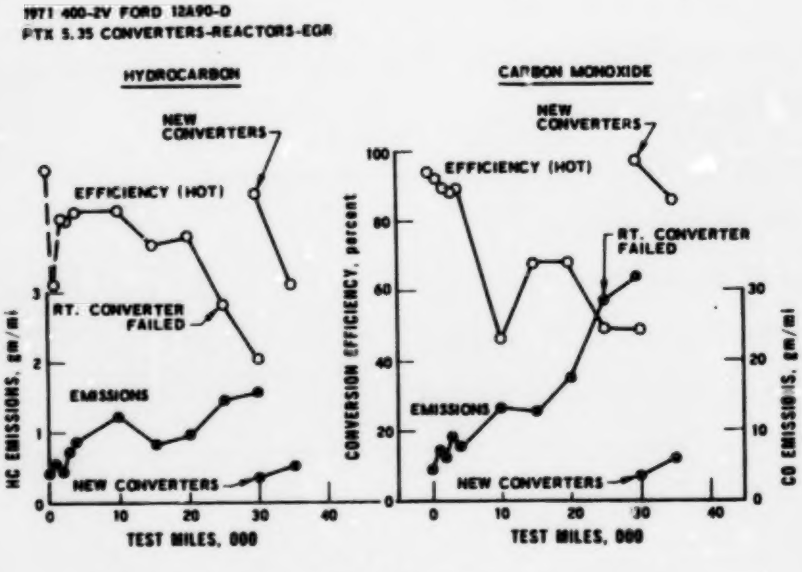

Figure 2-14. Ford AMA Durability Data

Table 2-15. Durability Test Vehicle Specifications (Vehicle No. 1A97-D)

Type: 1971 400-2V A/T Ford
Test Program: 1974 Model Year California Durability

Emission System Components

- Cylinder heads with port air injection
- EGR into the carburetor spacer, pickup before muffler and through a cooler
- 19 in^3 air pump with 1.37:1 drive ratio was used through the 30,000 mile test. Changed to 1.50:1 before the 35,000 mile test
- Single diaphragm distributor with production calibration. Initial timing 6°BTC
- Carburetor calibration No. ACE 39. Idle CO set to 2.5% at an idle speed of 560 rpm
- Monolithic PTX 5.2 converter used on left-hand side and monolithic PTX 5.35 used on right-hand side

Total Durability as of 4/20/72

- 50,000 miles, test completed

Emission Component Failures or Malfunctions During Durability Period

- EGR vacuum switch failed
- Schmelzer valve found defective and replaced
- Choke shaft replaced

Number of Emission Test Conducted

- 15 prior to start of durability
- 18 during the durability period

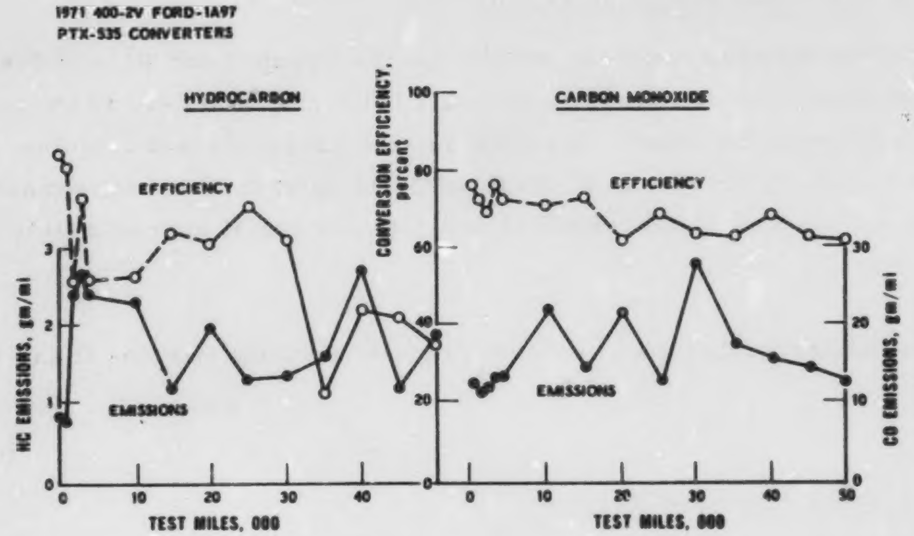

Figure 2-15. Ford AMA Durability Data

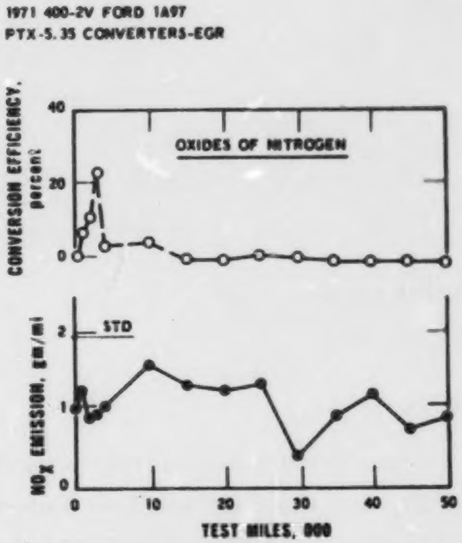

Figure 2-16. Ford AMA Durability Data

2.2.3.2.3.4 Best Emission Results

The best low mileage emission results for the Group II and III vehicles being tested at Riverside are shown in the table below. Results are for zero miles unless otherwise indicated. In addition to the Riverside test vehicles, data are also shown under Group III (dual catalysts only) for the best emission results achieved on a Maverick V-8 development car at approximately 125 miles.

Best Emission Results[1] -- Ford Alternate Systems (Groups II and III)

	Riverside		
	HC	CO	NO_x
Group II (Dual Cats. and Reactor)			
Maverick, 6 cyl.	0.22	3.23	1.76
Ford	0.36	3.72	2.17
F-100[2]	0.32	4.21	1.76
Lincoln	0.23	2.22	2.33
Group III (Dual Cats. Only)			
Maverick, 6 cyl	0.21	1.73	2.08
Ford	0.26	1.53	2.19
F-100[2]	0.32	1.71	2.09
Lincoln	0.28	1.59	2.10
Maverick, V-8	0.20	1.29	1.51

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[1] Average of two consecutive tests

[2] At 2,000 miles.

2.2.3.2.3.5 Test Data Variability

The Riverside test data for the Ford dual catalyst plus thermal reactor equipped vehicles (Group II), and the dual catalyst-only vehicles (Group III), exhibit a greater spread than do the data from the Ford first-choice system which employs the single catalyst. This is consistent with the Ford statement, (Ref. 2-9) that "systems with many specific control devices have greater variability as each added device contributes its own degree of variability." The small data sample size does not permit a meaningful evaluation of the coefficient of variation.

2.2.3.2.4 Fuel Consumption and Performance Penalties

Fuel consumption and performance penalties for the Ford alternate (Group II and III) systems were not discussed. Some performance information was provided for the 302-CID Maverick developmental vehicle. This vehicle is equipped with the dual catalyst system and is comparable to the Group III vehicle. At 5800 miles, the average driveability was reported as 6 (on a scale of 10), ranging from 5 on light acceleration to 7 at WOT. Fuel consumption penalties were not reported.

2.2.4 General Motors

2.2.4.1 First-Choice Systems

2.2.4.1.1 Special Design Features

The General Motors first-choice system comprises the following subsystems (Refs. 2-11 through 2-15):

- Catalytic converter (base metal/particulate)
- Secondary air supply (AIR)
- Exhaust gas recirculation (EGR)
- Engine modifications
  - Modified carburetor with altitude compensation and fast acting choke
  - Modified intake system with quick heat manifold to produce early fuel evaporation (EFE)
  - Modified exhaust system acting as a partial thermal reactor
  - Electronic ignition system
  - Modified spark timing

The system is illustrated in Figure 2-17. It was selected on the basis of the following considerations:

a. 1975 emission levels were approached at low mileage.

b. Many of the components use existing technology; the only exception is the catalytic converter.

c. The system can be readily modified for 1976 NO_x control.

d. The system involves a minimum number of vehicle compromises.

The base metal/particulate catalyst converter was selected over the noble metal/monolithic catalyst converter for a number of reasons. General Motors states that it is cheaper, more readily available, has better deterioration and durability characteristics, and is less subject to poisoning. The light-off (50 percent conversion efficiency) temperature is said to be about the same as the monolithic type at zero miles.

With regard to change in light-off temperature with use, GM 24-hour soak tests are reported to show that the light-off temperature of the noble metal converter increases linearly with increasing soak temperature, whereas the base metal catalyst retains its low light-off temperature at soak temperatures as high as 1800 °F. This is regarded as proof that the base metal pellet system has greater ability to withstand overtemperature conditions. In addition, the GM data indicate that the activity of the base metal catalyst starts at lower temperature.

Another GM consideration concerning the selection of the pelletized catalyst was that the pellets might be readily and cheaply replaced, an advantage that may be particularly significant if maintenance is authorized at mileage intervals under 50,000 miles.

The EFE manifold is used on the first-choice system in conjunction with an improved carburetor and choke components to improve the cold start emissions. The electronic ignition system is included to permit engine operation

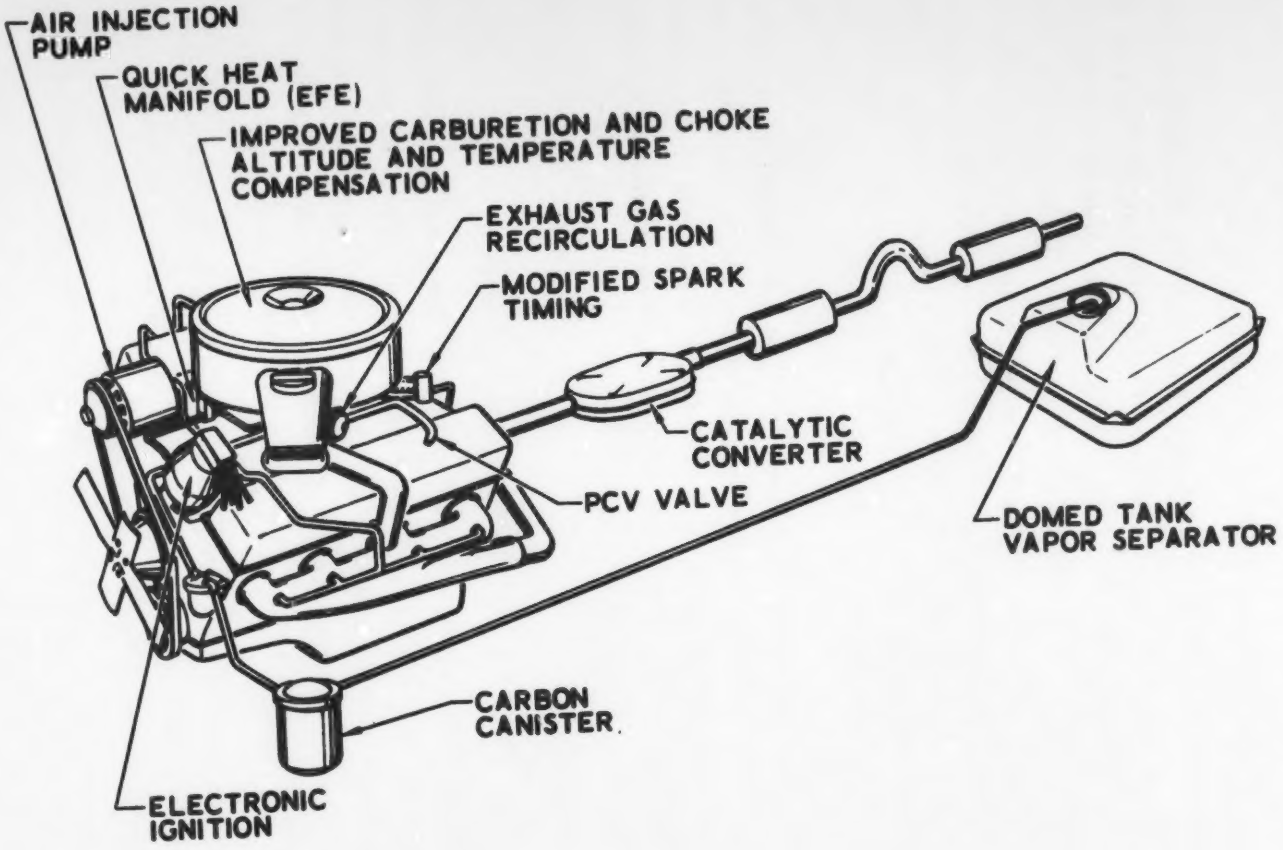
AIR INJECTION PUMP
QUICK HEAT MANIFOLD (EFE)
IMPROVED CARBURETION AND CHOKE ALTITUDE AND TEMPERATURE COMPENSATION
EXHAUST GAS RECIRCULATION
MODIFIED SPARK TIMING
CATALYTIC CONVERTER
PCV VALVE
DOMED TANK VAPOR SEPARATOR
CARBON CANISTER
ELECTRONIC IGNITION

Figure 2-17. General Motors First-Choice 1975 Emission Control System

with leaner air/fuel mixture ratios while still retaining acceptable driveability and improved reliability over the life of the vehicle.

2.2.4.1.2 Problem Areas and Plans for Resolution

Further development is said to be needed to improve the durability of the catalytic converter and of the EGR valve. Testing of these systems is being actively pursued. General Motors feels that physical durability of the pellets is no longer a problem. Catalyst shrinkage has been limited to 10 percent for a 24-hour soak at 1800 °F. Sulfur poisoning, which is a very serious problem at catalyst bed operating temperatures below 1300 °F, has been shown to be much milder above 1300 °F. For this reason GM may decide to operate their converter above 1300 °F instead of the present nominal operating temperature of 900 to 1200 °F.

Durability of the EGR valve is still not adequate and design improvements will be checked out during road testing under various loads. The EFE manifold and the electronic ignition systems are still at the engineering prototype level. More experimental work is required prior to committing a specific design to production.

2.2.4.1.3 Emissions

2.2.4.1.3.1 Test Programs and Vehicle Description

According to GM, a total of 380 catalytic converter systems have been built and tested during the last 2 years. Emission test results from 50 low mileage experimental systems were included in the GM submission. These encompass tests on a variety of catalytic converter types and makes, including base and noble metal pellet and noble metal monolithic designs.

For certification, General Motors requires a minimum of 13 cars to meet the 1975 Federal standards. In addition to the certification test fleet, GM will pre-test 13 similar vehicles to verify the emissions and durability. A concurrent test program will check out the cars from the standpoint of driveability, fuel consumption, safety, mechanical durability, etc., under customer driving and variable weather conditions. This will be done on the GM proving ground. Because of the large number of models, engines, and transmission options provided, the test program will be designed on a statistical basis to verify satisfactory performance and operation over the broad spectrum of hardware combinations. The number of cars to be tested in this program have not yet been determined.

In addition to the above, GM is operating a baseline test fleet of 18 vehicles to test the durability of the catalytic converter canister.

2.2.4.1.3.2 Test Procedures

All recent testing has been conducted using the 1975 CVS-CH Federal Test Procedure. Durability testing is accomplished using a modified AMA driving schedule.

2.2.4.1.3.3 Emission Data Summary

Low mileage emission data submitted by GM are shown in Table 2-16; high mileage data are presented in Table 2-17. Each entry represents a single test and should be viewed with due regard for the high degree of test-to-test variability discussed in Section 2.2.4.1.3.5.

For the most part, these data represent the experimental system vehicles which are closest to GM's description of the total first-choice package required for the 1975 model year vehicle. It will be noted that not all of the vehicles are equipped with the full complement of components for the first-choice system. Carburetor altitude compensation and electronic ignition components, which are among the missing items, are stated by GM to have little impact on EPA test emissions results. The quick heat EFE manifold is missing on many cars because of the lack of advanced design engine components available for experimentation. GM states that this is not particularly important in evaluating the emission performance of these vehicles since they are not equipped with the appropriate chokes for low CO EFE performance anyway.

Table 2-16. General Motors Low Mileage Emissions

		Oxidizing Catalyst		System Description							1975 CVS-CH Emissions, gm/mi(2)			
Car No.	Car & CID	Type(1)	Supplier	AIR	EGR	Mod. Carb.	EFE	Test Weight	Test Date	Test Mileage	HC	CO	NO_x	Status
61336	Chev. 350	BB	Grace Davex 117	x	x	x		4500	7-71	800	0.30	7.0	1.3	Co-op development (Arvin)
61341	Chev. 350	BB	Grace Davex 117	x	x	x		4500	8-71	400	0.50	7.0	1.1	Co-op development (Norris)
61340	Chev. 350	BB	Grace Davex 117	x	x	x		4500	8-71	150	0.60	10.0	1.4	Co-op development (Walker)
61355	Chev. 350	BN	Universal Oil PZ-2-168 R-5	x	x	x		4000	2-72	700	0.30	2.7	0.8	System development
61358	Chev. 350	BN	Universal Oil PZ-2-168 R-5	x	x	x	x	4500	1-72	80	0.33	2.4	0.9	System development
61317	Chev. 350	BB	Oxy-Catalyst G-623-71 No Prom.	x	x	x		4500	10-71	0	0.47(89)	6.7(75)	1.4	Durability test
61318	Chev. 350	BB	APCC	x	x	x		4500	12-71	0	0.25(76)	2.9(71)	1.9	Durability test
61319	Chev. 350	MN	Engelhard PTX-4	x	x	x		4500	8-71	0	0.13(84)	1.9(83)	1.3	Durability test
61339	Chev. 402	BB	Grace Davex 117	x	x	x		4500	10-71	100	0.37	12.8	0.8	System development
61329	Chev. 402	BB	Monsanto NBP-701094	x	x	x		4500	2-72	2,934	0.55	3.8	1.0	Durability test
61324	Chev. 402	BB	Grace Davex 117	x	x	x		4500	6-71	1,000	0.36	4.1	0.9	Crosscheck car
62504	Pont. 455	BB	Universal Oil PZ-1-224-1	x	x	x		4500	11-71	100	0.34	2.4	0.9	System development
62505	Pont. 455	BB	APCC	x	x	x	x	4500	4-72	6	0.20	0.8	1.4	System development
1938	Pont. 455	BB	Monsanto ECA-125	x	x	x	x	4500	12-71	400	0.41	5.4	1.5	System development
2586	Olds 350	BB	APCC 1259JX3-1X1	x	x	x		5000	2-72	42	0.28(83)*	7.3(67)*	3.7	Durability test
2611	Olds 350	BB	Universal Oil PZ-1-224-1	x	x	x		5000	1-72	1	0.24(82)*	9.1(55)*	1.9	Durability test
2541	Olds 350	BB	Oxy-Catalyst	x	x	x		5000	3-72	9	0.17(88)*	2.7(82)*	2.2	Durability test

See notes on last sheet.

Table 2-16. General Motors Low Mileage Emissions (Continued)

Car No.	Car & CID	Oxidizing Catalyst		System Description				Test Weight	Test Date	Test Mileage	1975 CVS-CH Emissions, gm/mi(2)			Status
		Type(1)	Supplier	AIR	EGR	Mod. Carb.	EFE				HC	CO	NO_x	
61420	Olds 455	BN	Universal Oil PZ-2-168-R-5	x	x	x		5000	12-71	100	0.20	2.6	1.0	Durability test
									1-72	275	0.40	5.2	1.5	
									1-72	400	0.40	2.6	1.0	
									2-72	860	0.27	3.9	1.1	
									2-72	874	0.27	3.2	1.1	
									3-72	1,126	0.26	2.1	1.2	
									3-72	1,134	0.25	2.9	1.0	
									4-72	2,287	0.37	3.2	1.1	
62403	Olds 455	BB	APCC 1259 JX3-1X1	x	x	x		5000	2-72	118	0.45	5.4	1.0	System development
62411	Olds 455	BB	APCC 1259JX3-1X1	x	x	x		5500	1-72	240	0.52	5.0	0.9	System development
2826	Buick 455	BB	Degussa OM56ET	x	x			5000	3-72	10	0.38(78)*	3.5(85)*	3.3	Durability test
2242	Buick 350	BB	APCC 1259JX3-1X1	x	x	x		4500	3-72	0	0.56	5.9	1.6	Durability test
4231	Buick 350	BB	Oxy-Catalyst	x	x	x		4500	2-72	0	0.64	6.8	2.5	Durability test
62102	Buick 455	BB	APCC 1259JX3-1X1	x	x	x	x	5500	2-72	1,689	0.63	3.2	1.0	System development
2827	Buick 455	BB	Grace Davex 142 SMR 7-3881	x	x			5000	2-72	88	0.27(79)*	4.2(71)*	3.7	Durability test
62115	Skylark 455	BB	APCC 1259JX3-1X1	x	x	x	x	4500	4-72	280	0.70	2.5	0.9	System development
9168	Buick 455	BB	Universal Oil PZ-1-225-1	x	x	x		5000	3-72	650	0.31	2.7	1.7	System development
8245	Buick 455	BB	Universal Oil PZ-4-214 R-14	x	x	x		5000	2-72	300	0.23(81)*	2.8(91)*	1.4	System development
61125	Buick 455	BB	Monsanto ECA-125	x	x	x		5000	2-72	2,500	1.00	7.6	0.9	System development
5274	Buick 455	BB	Universal Oil PZ-4-214 R-14	x	x	x		5000	3-72	300	0.44	2.8	1.5	System development
8195	Buick 455	BB	Universal Oil PZ-4-214 R-14	x	x	x		5000	3-72	1,644	0.25	2.5	1.0	System development
2828	Buick 455	BB	Monsanto ECA-141	x	x			5000	3-72	0	0.14(89)*	3.8(75)*	3.1	Durability test

See notes on last sheet.

Table 2-16. General Motors Low Mileage Emissions (Continued)

Car No.	Car & CID	Oxidizing Catalyst		System Description				Test Weight	Test Date	Test Mileage	1975 CVS-CH Emissions, gm/mi(2)			Status
		Type(1)	Supplier	AIR	EGR	Mod. Carb.	EFE				HC	CO	NO_x	
2822	Buick 455	BB	Oxy-Catalyst G-1313	x	x			5000	1-72	0	0.41(67)*	5.7(45)*	3.5	Durability test
2823	Buick 455	BB	Grace Davex 142 SMR 7-3881	x	x			5000	1-72	0	0.20(84)*	4.7(51)*	2.9	Durability test
2824	Buick 455	BB	Oxy-Catalyst G-1313	x	x			5000	1-72	0	0.33(81)*	3.0(74)*	3.7	Durability test
2825	Buick 455	BB	Oxy-Catalyst	x	x			5000	3-72	0	0.31(79)*	4.6(74)*	3.3	Durability test
BAK	Buick 455	BB	Universal Oil PZ-4-214 R-14	x	x			5000	11-71	21	0.17(88)*	1.8(87)*	3.7	Durability test
934	Buick 455	BB	Universal Oil PZ-1-224-1	x	x			5000	1-72	0	0.25	2.7	2.0	Durability test
933	Buick 455	BB	Oxy-Catalyst	x	x			5000	11-71	0	0.19	1.8	2.4	Durability test
61202	Cad 472	BB	Monsanto ECA-125	x	x	x	x	5500	2-72	1,000	0.92	6.8	0.9	System development
61206	Cad 472	BB	Monsanto ECA-125	x	x	x	x	5500	2-72	1,200	0.51	4.6	0.9	System development
61201	Cad 472	BB	Universal Oil PZ-4-214 R-14	x	x	x		5000	1-71	50	0.16	5.9	1.0	Durability test
61203	Cad 472	BB	APCC 1259JX4-1X1	x	x	x		5500	2-72	300	0.25	6.0	0.9	System development
1246	Cad 500	BB	Grace Davex 117	x	x	x		5500	1-72	0	0.27	1.7	2.9	System development
2222	Cad 500	BB	APCC 1259JX3-1X1	x	x	x		5500	1-72	0	0.35	1.1	2.0	Durability test
1420	Opel 1.9 lit.	MN	Engelhard PTX	x	x	x		2500	2-72	0	0.23	2.7	1.5	System development
1450	Opel 1.9 lit.	BB	Grace Davex 117	x	x	x		2500	12-71	0	0.53	10.4	1.7	Durability test

Note: Emissions data reported for each vehicle represent one test only.

(1) Type:
BB = Bulk base metal
BN = Bulk noble metal
MN = Monolith noble metal
MB = Monolith base metal
APCC = Air Products and Chemicals Co (Houdry)

(2) Catalyst conversion efficiency shown in parentheses - %

* Efficiency calculated from with and without converter tests not from simultaneous test.

Table 2-17. General Motors High Mileage Emissions

Car No.	Car & CID	Oxidizing Catalyst		System Description				Test Weight	Test Date	Test Mileage	1975 CVS-CH Emissions, gm/mi$^{(2)}$			Status
		Type$^{(1)}$	Supplier	AIR	EGR	Mod. Carb.	EFE				HC	CO	NO$_x$	
61319	Chev. 350	MN	Engelhard PTX-4	x	x	x		4500	8-71	0	0.13(84)	1.9(83)	1.3	
									11-71	8,424	0.51(65)	4.9(77)	1.4	
									2-72	21,527	0.55(76)	5.5(70)	1.6	Test continuing
61318	Chev. 350	BB	APCC	x	x	x		4500	12-71	0	0.25(76)	2.9(71)	1.9	
									4-72	21,178	0.87(58)	4.1(64)	1.6	Test continuing
61317	Chev. 350	BB	Oxy-Catalyst G-623-71	x	x	x		4500	10-71	0	0.47(89)	6.7(75)	1.4	
									3-72	32,014	1.20(73)	13.6(50)	1.4	Test continuing
Dev.	Chev. 400	BB	Oxy-Catalyst	x				5000	12-71	0	0.19	2.0	5.9	
									3-72	5,544	0.51	5.4	5.3	Test continuing
61329	Chev. 402	BB	Monsanto NBP-70194	x	x	x		4500	7-71	126	0.47	4.0	1.1	
									8-71	229	0.91	3.2	1.5	
									9-71	627	0.74	4.5	1.2	
									10-71	825	0.85	2.5	1.1	
									2-72	2,934	0.55	3.8	1.0	
									4-72	5,550	0.55	8.8	1.1	Test continuing
2014	Olds 350	BB	Grace-Davex 142 SMR-7-3881		x	x		4500	2-72	20	0.59(71)*	11.1(47)*	2.1	
									3-72	3,034	0.70	11.6	2.0	
									4-72	6,436	0.89(54)*	15.5(10)*	2.9	Test continuing
2611^a	Olds 350	BB	Universal Oil PZ-1-224-1	x	x	x		5000	1-72	1	0.24(82)*	9.1(55)*	1.9	
									2-72	6,145	1.4	14.6	2.6	Terminated: catalyst lost
		BB	Grace - Davex 142 SME 7-3881		x	x	x	5000	2-72	0	0.40(71)*	9.0(39)*	2.3	
									3-72	6,337	0.52	17.7	2.4	
									4-72	12,022	0.91	24.0	2.2	Test continuing
2494^b	Olds 455	BB	Oxy-Catalyst			x		5000	1-72	0	0.20(93)*	9.2(27)*	3.2	
									2-72	2,548	0.62	11.0	4.2	
									3-72	4,615	0.53	8.2	4.5	
									3-72	6,097	0.63	7.2	3.5	
									4-72	9,280	1.02	7.7	3.3	Test continuing
2823^a	Olds 455	BB	APCC 1259JX3-1X1		x	x'		5500	1-72	10	0.34(72)*	10.7(16)*	2.1	
									1-72	3,336	0.41	10.3	2.0	
									2-72	8,927	0.62(51)*	11.6(30)*	2.0	Test continuing
2249^a	Olds 455	BB	Oxy-Catalyst		x	x		4500	1-72	54	0.27(78)*	10.8(70)*	1.7	
									4-72	6,400	0.48	11.9	1.3	Test continuing
2850	Olds 455	BB	Oxy-Catalyst		x	x		5500	1-72	0	0.31(75)*	10.5(-8)*	2.0	
									2-72	3,235	0.34	9.7	2.6	
									2-72	6,447	0.55	7.8	1.2	
									3-72	12,257	0.53	9.2	2.6	
									4-72	18,000	0.58	7.4	2.7	Test continuing

See notes on last sheet.

Table 2-17. General Motors High Mileage Emissions (Continued)

		Oxidizing Catalyst		System Description							1975 CVS-CH Emissions gm/mi$^{(2)}$			
Car No.	Car & CID	Type$^{(1)}$	Supplier	AIR	EGR	Mod. Carb.	EFE	Test Weight	Test Date	Test Mileage	HC	CO	NO_x	Status
2233	Olds 455	BB	APCC 1259JX3-1X1		x	x		4500	12-71	0	0.31(85)*	5.6(51)*	2.1	
									1-72	14,227	0.48	10.7	1.6	
									1-72	19,868	0.52	11.7	1.6	
									2-72	24,304	0.56(10)*	8.6(18)*	1.9	Discontinued; high deterioration
									3-72	30,037	0.73	10.6	2.3	
4231	Buick 350	BB	Oxy-Catalyst	x	x	x		4500	2-72	0	0.64	6.8	2.5	
									2-72	1,600	0.76	7.7	4.2	
									3-72	4,200	0.66	8.2	3.7	
									4-72	7,600	0.81	9.5	3.7	Test continuing
62124	Buick 455	BB	APCC 1259JX3-1X1	x		x		5000	2-72	43	0.38(75)	4.1(75)	5.6	
									2-72	2,910	1.08(48)	7.2(60)	5.3	
									3-72	7,280	0.43(68)	3.6(67)	4.9	
									3-72	10,097	0.98(43)	9.9(50)	5.9	Catalyst being changed
62125	Buick 455	BB	APCC 1259JX3-1X1	x		x		5000	2-72	32	0.64(67)	3.6(78)	5.7	
									2-72	3,201	0.72(52)	4.0(67)	5.7	
									3-72	7,198	1.16(44)	7.1(59)	5.8	
									3-72	10,469	1.24(36)	9.6(54)	5.7	Catalyst being changed
62126	Buick 455	BB	APCC 1259JX3-1X1	x		x		5000	2-72	33	0.54(78)	2.1(89)	6.0	
									2-72	3,381	0.65(56)	3.3(56)	5.5	
									3-72	7,096	0.67(58)	3.8(50)	4.9	
									3-72	10,079	0.71(59)	3.2(50)	5.1	Catalyst being changed
933	Buick 455	BB	Universal Oil Products PZ-4-214-R-14	x	x			5000	11-71	0	0.19	1.8	2.4	
									12-71	7,798	0.36	4.4	2.8	
									1-72	19,106	0.44	4.3	2.0	
									2-72	27,161	0.51	5.6	2.2	
									2-72	38,661	2.71	9.3	2.6	
									3-72	43,179	0.90	7.5	2.3	
									4-72	46,301	0.78	11.7	2.1	Test stopped
BAK	Buick 455	BB	Universal Oil Products PZ-4-214-R14	x				5000	11-71	21	0.17(88)*	2.8(87)*	3.7	
									11-71	31	0.17	3.3	3.7	
									1-72	2,805	0.47	6.3	3.7	
									4-72	12,980	0.36	6.6	1.6	Test continuing
931	Buick 455	BB	APCC 1259JX3-1X1	x	x			5000	12-71	0	0.29	2.3	6.0	
									1-72	7,544	0.64	6.7	4.0	Test stopped
2222	Cad. 500	BB	APCC 1259JX3-1X1	x	x	x		5500	1-72	0	0.35	1.1	2.0	
									1-72	2,000	0.40	2.3	1.9	
									2-72	4,000	0.35	3.2	2.1	
									4-72	8,000	0.32	4.6	2.6	Test continuing
1450	Opel 1.9 lit.	BB	Grace Davex 117	x	x	x		1500	12-71	0	0.53	10.4	1.7	
									1-72	12,000	0.73	10.8	2.2	
									2-72	23,000	1.2	22.9	2.5	Test continuing

(1)Type:
BB = Bulk base metal
BN = Bulk noble metal
MN = Monolith noble metal
MB = Monolith base metal

(2)Catalyst conversion efficiency shown in parentheses - %.

Note: Emissions data reported for each vehicle represent one test only.

*Efficiency calculated from with and without converter tests, not from simultaneous test.

APCC = Air Products and Chemicals Co. (Houdry)

Non-AMA Durability Schedules
a = PG (Proving Ground), Regular Schedule
b = Hill Schedule, Milford PG

Most of the vehicles shown in Tables 2-16 and 2-17 were equipped with base metal/bead catalytic converters (designated BB). Included among these first-choice system test results are GM data obtained for other catalytic converter designs. These systems, which may be regarded as GM alternate system candidates, include the platinum/bead system (designated BN) and the platinum/monolith (Engelhard) system (designated MN).

Whereas GM stated in the suspension request hearing that zero mile emissions were lower for the noble metal/monolith catalyst, but that the deterioration factor is more severe than for its first-choice (base metal/bead) catalyst, the test results shown in Tables 2-16 and 2-17 do not always support this statement. For example, the emission levels for Vehicles 62505 and 933 (base metal/bead) are comparable to those for Vehicle 61319 (platinum/monolith) at low mileage. At high mileage the emissions of Vehicles 933 and 61319 are similar.

From the data displayed in Table 2-16, GM observes that its first-choice (BB) system shows the potential of achieving low mileage emission levels of about 0.3 gm/mi HC, 2.5 gm/mi CO, and 1.5 gm/mi NO_x. However, GM emphasizes that none of the systems tested has been built from production machinery nor have attempts been made to duplicate these tests on different vehicles. Vehicles with these initial levels are shown in Table 2-17 to exceed the 1975 standards before 5000 miles are accumulated.

High mileage emissions are shown in Table 2-17. Vehicles appearing in this list were driven over 4000 miles. It may be seen that all of the systems which performed well at or below 4000 miles exceed the 1975 Federal specifications at relatively low mileage.

As yet, none of the GM converters has achieved the 50,000-mile durability requirement. The maximum reported accumulated mileage for first-choice systems was 46,301 miles, which was achieved with a 455-CID Buick equipped with a UOP base metal/pellet catalytic converter designated PZ-4-214-R-14. Emission levels at this point were 0.78, 11.7, and 2.1 gm/mi for HC, CO, and NO_x, respectively; the test was terminated here.

One other high mileage data point, not included in Table 2-17 because information concerning test procedures is lacking, may be mentioned. This data point appeared in Attachment 2, Volume 1 of the GM supplementary material submitted during the public hearings and was part of the data delineated in the testimony of David Hawkins on April 26, 1972. The data concern GM Test #472, which reports emission levels for a 455 CID, 1971 Buick as 0.37, 2.42, and 3.44 gm/mi for HC, CO, and NO_x, respectively, at an accumulated mileage of 27,600 miles. The maximum mileage reported for this vehicle was 45,300 miles, at which point the respective emissions were 0.53, 3.5, and 4.0 gm/mi. General Motors states that these data are based on the 7-mode test procedure. The vehicle emissions package included a Monsanto ECA-125 catalytic converter. Other emissions equipment was not specified.

2.2.4.1.3.4 Best Emission Results

Sixteen vehicles listed in Table 2-16 have all three pollutants (HC, CO, and NO_x) within the 1975 Federal standards at low mileage. The lowest overall emission levels were obtained with car #62505 (Pontiac, 455 CID) equipped with an Air Products base-metal/bead catalyst converter (HC = 0.20 gm/mi, CO = 0.8 gm/mi, NO_x = 1.4 gm/mi). Another first-choice catalyst type which appears to be successful on a low mileage basis is the UOP base metal/bead catalyst designated PZ-1-224-1. Other systems which show promise include Oxy-catalyst and W.R. Grace (Davex 117) designs.

None of the high mileage results reported by GM meets the 1975 standard. Good emission results at lower mileage levels were obtained with an Air Products catalyst #1259JX3-1X1 (base metal/bead) mounted in a Cadillac (500 CID). At 4000 miles the emissions were still within standards. At 8000 miles HC and NO_x emissions were still within standards (0.32 and 2.6 gm/mi, respectively) but CO had exceeded the standard (4.6 gm/mi).

The best high mileage results, from the standpoint of mileage accumulated, would appear to be the Test #472 data discussed in the previous section and quoted as 0.37, 2.42 and 3.44 gm/mi for HC, CO, and NO_x, respectively, at 27,600 miles (7-mode). This test point, it may be noted, was fortuitously selected from among other high mileage data which exceed the standards.

2.2.4.1.3.5 Test Data Variability

General Motors states that sixteen repetitive tests on one car showed a range of 67 percent for HC measurements and 200 percent for CO measurements. The following one-standard-deviation test-to-test variations are quoted by General Motors: HC = ±8.6 percent, CO = ±12.4 percent, NO_x = ±15 percent. The corresponding test cell-to-test cell variations are HC = ±24.1 percent, CO = ±20 percent, NO_x = ±15 percent. The data variability from car to car of the same model is not given.

2.2.4.1.4 Fuel Consumption and Performance Penalties

The 1975 emission components and engine modifications cause an increase of approximately 10 percent in fuel consumption.

Efforts to reduce cold start emissions have resulted in very marginal vehicle driveability during cold operation. Frequent stalls after cold start and during the warmup period have been encountered. The loss in power at full throttle is not anticipated to be large unless high EGR rates must be used at full throttle for NO_x control.

2.2.4.2 Alternate Systems

2.2.4.2.1 Special Design Features

General Motors states that a final selection of the first-choice system catalytic converter design has not been made, and that evaluations are proceeding on improved catalyst formulations as well as other catalytic converter designs. Among the latter are noble metal pellet and monolithic types.

General Motors claims that the design of its emission control package permits an easy switch to the monolithic type of catalytic converter if superior emissions performance and durability indicate the desirability of such a change.

Another possible GM alternate system utilizes a thermal reactor for some vehicles like the Vega (4-cylinder engine). Air/fuel conditions required for reactor operation offer the advantage of less initial release of NO_x, thereby requiring less aftertreatment by reducing catalyst systems planned for 1976.

2.2.4.2.2 Problem Areas and Plans for Resolution

Two major problems encountered by GM with the noble metal/monolith catalyst converter are high deterioration rates and susceptibility to overtemperature and to poisoning. Improved catalyst formulations continually are being tested and will be used if found to be superior to the first-choice system.

Problems encountered with the manifold reactor are driveability and packaging. The need of extensive insulation to maintain high oxidizing temperatures (1500-2000 °F) affects the problem of engine compartment packaging. More experience in the use of high efficiency insulation materials is said to be needed. Air requirements for the thermal reactor exceed those for the catalytic converter; a larger air pump is therefore required. Satisfactory materials for manifold reactor durability have not yet been found.

2.2.4.2.3 Emissions

2.2.4.2.3.1 Test Programs and Vehicle Description

The test program description provided in Section 2.2.4.1.3.1 is generally applicable to the second-choice system. General Motor's experimental exhaust manifold reactor vehicles were a 350-CID Chevrolet and a 140-CID Vega.

2.2.4.2.3.2 Test Procedure

The 1975-CVS-CH Federal Test Procedure was used. Durability data for the GM alternate systems are not provided except for the vehicle utilizing an Engelhard platinum/monolith catalyst converter. This system was tested on a modified AMA test track.

2.2.4.2.3.3 Emission Data Summary

The emission data reported by GM for alternate catalytic converter systems of the noble metal bead and monolithic designs are included in Tables 2-16 and 2-17. Additional GM data covering the performance of the noble metal/monolithic Engelhard PTX system were reported in the Engelhard submittal and are presented in Table 2-18. Table 2-19 provides low mileage emission data for the exhaust manifold reactor system.

2.2.4.2.3.4 Best Emission Results

The only data for the noble metal bead-type catalyst (BN) was reported for the UOP PZ-2-168-R-5 design. This catalyst has accumulated 2287 miles within standards (Car 61420 in Table 2-16). High mileage data for this system was not provided.

The Engelhard platinum/monolith converter (Car 61319 in Tables 2-16 and 2-17) shows very good low mileage emission results: 0.13, 1.9, and 1.3 gm/mi for HC, CO, and NO_x, respectively. The 1975 standards were exceeded for HC at 4000 miles, for CO at 5500 miles, and for NO_x at 6000 miles. Referring to the GM data reported by Engelhard and shown in Table 2-18, Car 17934, described as a 455-CID 1971 Buick Estate Wagon equipped with two Engelhard PTX-423S monolithic converters, is indicated to have accumulated 24,630 miles at emission levels of 0.34, 3.09, and 2.54 gm/mi for HC, CO, and NO_x, respectively. Engelhard further reports that this system accumulated a total of 70,000 miles, at which point the respective emissions were 0.85, 8.7, and 3.5 gm/mi.

Table 2-18. General Motors Mileage Emission Data Reported by Engelhard (GM Alternate Systems)

Car No.	Car and CID	Oxidizing Catalyst		System Description				Test Weight	Test Date	Car Mileage	Catalyst Mileage	1972-CVS-C Emissions gm/mi			Comments
		Type(1)	Supplier	AIR	EGR	Mod Carb.	EFE					HC	CO	NO_x	
17934	Buick 455 Estate Wagon	MN	Engelhard PTX-423S	x	x	x		5000	5/14/71	13,092	0	0.12	1.88	2.39	High speed tire test at GM Arizona test track. Average exhaust temperature during emission run 1230°F
									5/26/71	18,254	5,162	0.34	2.05	2.19	
									6/11/71	24,527	11,435	0.48	3.01	2.43	
									6/22/71	28,721	15,629	0.31	3.33	2.67	
									7/1/71	33,252	20,160	0.55	3.76	2.08	
									7/16/71	37,722	24,630	0.34	3.09	2.54	
									2/27/72		70,000	0.85(2)	8.7(2)	3.5(2)	After completion of 70,000 mi. tested on AC Test Car 067 at Detroit

(1)Type: MN = monolith/platinum (0.2%)

(2)1975-CVS-CH test procedure; average of 2 tests.

Table 2-19. Exhaust Manifold Reactor System Vehicles (GM Alternate Systems)

Car	Engine CID	Emissions, gm/mi*			System Description
		HC	CO	NO_x	
Chev.	350	0.1	3.9	0.8	Glass insulated, Air, EGR
Vega	140	0.2	2.8	0.39	Sand insulated, Air, EGR
Vega	140	0.24	3.0	0.39	Sand insulated, Air, EGR
Chev.	350	0.28	1.1	0.6	Reducing catalyst converter, Air, EGR (1976 System)
Chev.	350	0.1	1.2	1.2	Reducing catalyst converter, Air, EGR (1976 System)

*1975 CVS-CH Procedure

Best low mileage emissions for the exhaust manifold reactor system (without reducing catalyst) were 0.2, 2.8, and 3.9 gm/mi for HC, CO, and NO_x, respectively. No high mileage emissions for the exhaust manifold reactor system were provided.

2.2.4.2.3.5 Test Data Variability

The available data do not permit a statement to be made concerning test data variability. Variations are expected to be of the same order of magnitude as described for the GM first-choice system in Section 2.2.4.1.3.5.

2.2.4.2.4 Fuel Consumption and Performance Penalties

The second-choice catalytic converter system is expected to change the fuel consumption and affect performance to the same degree reported for the first-choice system in 2.2.4.1.4. In the case of the exhaust reactor manifold system, the fuel consumption penalty is expected to be more severe because the engine must be operated with rich air/fuel ratios to sustain efficient reactor operation. Operation at high EGR to reduce NO_x seriously deteriorates vehicle performance. Compared to the current production vehicle, the Vega manifold reactor system shows a 50 percent increase in the time required to accelerate from 0 to 60 mph.

2.2.5 International Harvester

2.2.5.1 First-Choice Systems

2.2.5.1.1 Special Design Features

The system presently envisaged by International Harvester as a first-choice selection would consist of an oxidizing catalytic converter, advanced EGR, and engine modifications, including advanced carburetion and a quick heat manifold. The advanced EGR system utilizes EGR rate/load proportioning calibrations as well as venturi signal proportional amplifiers. Neither the advanced EGR nor advanced fuel systems are yet available in the form of production prototypes; therefore, modifications to current hardware are being used (Refs. 2-16, -17) on all test vehicles for these items.

The selection of a specific catalytic converter has not yet been made by International Harvester. Primary effort to date has concentrated on an AC-Delco base metal/pelletized catalyst packaged by the Walker Manufacturing Company, and an Engelhard noble metal monolithic catalyst, also packaged by Walker. International Harvester does not plan to manufacture the catalyst container but rather will procure it from an outside vendor.

2.2.5.1.2 Problem Areas and Plans for Resolution

International Harvester has not yet met the 1975 emission standards, even with zero mile vehicles. This is attributed to the low horsepower-to-weight ratio of the International Harvester vehicles which results in high average engine load factors with resulting high exhaust gas temperatures. Progress in limiting maximum gas temperature entering the catalyst, while still maintaining adequate chemical energy input during lighter load phases, has resulted in increased cold start emissions.

2.2.5.1.3 Emissions

2.2.5.1.3.1 Test Programs and Vehicle Description

International Harvester is continuing the evaluation of emission control systems as components become available. New catalytic converters are undergoing test as they are received from outside vendors. A Matthey Bishop noble/metal catalyst on a Corning extruded monolithic substrate is one of the configurations being examined. Test results from this converter are not reported. All high mileage emission data reported for the first-choice system have been accumulated on the 5500-lb inertia weight Travelall vehicles, equipped with either the AC-Delco base metal/pelletized converter, the Engelhard noble metal/monolithic (stacked) converter, or the W.R. Grace noble metal/monolithic (spiral wound) converter. All high mileage data have been accumulated in accordance with the AMA durability schedule.

2.2.5.1.3.2 Test Procedures

Test data reported by International Harvester conform to the 1975 CVS-CH test procedure.

2.2.5.1.3.3 Emission Data Summary

First-choice system low mileage emission data reported by International Harvester (Reference 2-16) was designated as a range of "representative" emission levels as follows:

International Harvester First-Choice System--
"Representative" Emission Levels

HC	0.3 - 0.5 gm/mi
CO	4.5 - 8.8 gm/mi
NO_x	2.4 - 3.1 gm/mi

AMA durability (high mileage) test results are reported for tests conducted on two different 5500-lb inertia weight vehicles as shown in Table 2-20. In no case has the 1975 standard for CO been achieved.

2.2.5.1.3.4 Best Emission Results

The best emission results reported by International Harvester for their first-choice system were achieved at zero miles on Travelall Vehicle #1 shown in Table 2-20. These were 0.35 gm/mi HC, 4.5 gm/mi CO, and 2.5 gm/mi NO_x.

2.2.5.1.3.5 Test Data Variability

The material presented by International Harvester does not permit a statement concerning data variability to be made.

2.2.5.1.4 Fuel Consumption and Performance Penalties

International Harvester estimates that the fuel economy for 1975 vehicles will be 10-15 percent below that of the 1972 vehicles (Ref. 2-16). To offset the anticipated loss in vehicle driveability and power, an increase in engine displacement of approximately 80 in.^3 is estimated to be required. New engines are in the development stage and are scheduled for production in the 1975 model year vehicles.

Table 2-20. High Mileage Emission Results – International Harvester First-Choice System

Vehicle	Miles	Emissions, gm/mi*			Remarks
		HC	CO	NO_x	
Travelall #1 392 CID Manual Transmission	0	0.45	4.4	3.0	AC-Delco base metal converter
	4000	0.46	10.4	4.2	Inadvertent use of leaded fuel suspected
	8000	0.77	12.7	2.3	
	12000	0.83	12.4	2.5	
	16000	0.83	11.4	2.6	
	0	0.35	4.5	2.5	Engine tuned, converter recharged
	4000	0.63	8.8	2.4	
	8000	0.63	10.3	2.5	
	12000	0.68	9.2	2.3	Test Continuing
Travelall #2 392 CID Automatic Transmission	0	0.35	4.6	3.1	AC-Delco base metal converter
	4000	0.33	4.7	--	
	8000	0.49	5.7	2.5	
	12000	0.53	7.5	3.6	
	16000	0.69	11.7	4.7	
	20000	0.51	8.8	3.0	

*1975 CVS-CH test procedure

2.2.5.2 Alternate Systems

2.2.5.2.1 Special Design Features

The system being evaluated by International Harvester on a second-choice basis consists of a thermal reactor, EGR, and an advanced fuel system with a fast heat manifold. Although the degree of control of HC and CO has not been at all satisfactory to date, it is the opinion of International Harvester that the thermal reactor represents a reliable system which is more suitable to the heavy duty nature of its product.

An additional system being developed in a parallel program involves a combination of the first- and second-choice systems; i.e., catalytic converter, thermal reactor, EGR, air injection, and engine modifications.

2.2.5.2.2 Problem Areas

Problems related to the International Harvester alternate systems were not discussed in specific terms. Extremely poor CO control with the thermal reactor system has been encountered, along with poor performance, driveability, emission control durability, and fuel economy. As is the case with the first-choice system, International Harvester is experiencing a great deal of difficulty in achieving the 1975 CO standards.

2.2.5.2.3 Emissions

2.2.5.2.3.1 Test Programs and Vehicle Description

All data reported for International Harvester are based on the 1975 CVS-CH test procedure unless otherwise indicated.

2.2.5.2.3.2 Emission Data Summary

Low mileage emission data reported by International Harvester for their second-choice system were designated in Ref. 2-16 as a range of "representative" emission levels as follows:

International Harvester Second-Choice System--
"Representative" Emission Levels

HC	0.37 - 1.0 gm/mi
CO	14.8 - 22.3 gm/mi
NO_x	1.2 - 2.8 gm/mi

High mileage emission data were reported for two Travelall vehicles equipped with the thermal reactor/EGR second-choice system. These data are shown in Table 2-21. Vehicle 257, which had no overtemperature protection device, was tested with 5 percent EGR. The reactor core was fabricated from 185R chrome aluminum alloy. The thermal reactors were removed for inspection at 24,000 miles. The left reactor core runners were found to be eroded and the core assembly severely warped. High underhood temperatures resulted in premature ignition wire failures. Vehicle 399 was tested with 8 percent EGR. This vehicle was equipped with an overtemperature protection system. Test data were not reported at intermediate mileage points for this vehicle. Reactor casting life was reported as unacceptable; cracking was observed at 2000-[illegible]000 miles.

Only limited emission data are available for the International Harvester second alternate system (thermal reactor, catalytic converter, EGR, air injection and engine modifications). "Representative" emission levels were reported to be 0.63 gm/mi HC, 3.5 gm/mi CO, and 0.77 gm/mi NO_x. No details regarding test mileage, converter type, or other specific information were provided.

Table 2-21. High Mileage Emission Data – International Harvester Second-Choice System

Vehicle	Miles	Emissions gm/mi* HC	CO	NO_x	Remarks
Travelall #257	0	0.41	22.3	1.78	5% EGR, 1972 distributor
	4,000	0.66	22.8	2.20	
	8,000	1.42	18.9	2.83	
	12,000	0.52	21.7	2.81	
	16,000	0.37	15.7	2.76	
	20,000	4.84	86.2	1.27	Engine miss-fire noted
	20,000	0.70	14.0	2.65	Recheck with new spark plugs and ignition wires, carburetor cleaned.
	24,000	1.07	21.1	1.96	Miss-fire detected on first part of test.
Travelall #399	0	0.56	14.8	1.98	8% EGR
	25,794	1.75	42.3	1.53	

*1975 CVS-CH test procedure

2.2.5.2.3.3 Best Emission Results

The best emission results reported by International Harvester for its alternate systems may be summarized as follows:

International Harvester Alternate Systems --
Best Emission Results

System	Miles	Emissions, gm/mi HC	CO	NO_x
EGR + AI + TR	16,000	0.37	15.7	2.76
EM + EGR + AI + TR + OC	Not specified	0.63	3.5	0.77

2.2.5.2.3.4 Test Data Variability

No statement concerning test data variability can be made.

2.2.5.2.4 Fuel Consumption and Performance Penalties

Fuel consumption and performance penalties for the alternate International Harvester systems are not discussed.

2.2.6 Alfa Romeo

2.2.6.1 First-Choice System

2.2.6.1.1 Special Design Features

Alfa Romeo did not identify a candidate 1975 system (Ref. 2-18). Test results reported by UOP (Ref. 2-19) for a 4-cylinder 2.0 liter overhead cam engine equipped with a 60 in^3 PZ-216 UOP catalyst were 0.44, 2.69, and 1.83 gm/mi for HC, CO, and NO_x respectively, by 1975 CVS-CH procedures (averages of two tests). Mileage associated with these results was not specified.

2.2.7 BMW

2.2.7.1 First-Choice System

2.2.7.1.1 Special Design Features

The 1975 system projected for use by BMW will consist of engine modifications, EGR, air injection, and an oxidation catalyst. The lowest emission data obtained, but not reported, approximate the 1975 standards (Ref. 2-18).

2.2.8 British Leyland Motor Corporation

2.2.8.1 First-Choice System

2.2.8.1.1 Special Design Features

British Leyland states that it is impracticable and uneconomical to select a system suitable only for 1975; accordingly, it has made a major effort to develop a 1975 emission control package which, with the add-on of a reducing catalyst, would also serve for use in 1976 (Refs. 2-20, -21, -22).

The British Leyland first-choice system for 1975 comprises an oxidizing catalytic converter (type not selected, but probably a platinum monolith), secondary air injection, and engine modifications. Thermal reactors have been rejected as being unable to meet the 1976 standards and were not needed for the 1975 standards. Exhaust gas recirculation (EGR) will not be used on most models (possible exceptions include the Jaguar). The 1975 NO_x standard is being met with ignition timing retardation and by reducing engine compression ratio to 8:1.

British Leyland has contracted with Imperial Chemical Industries (ICI) for technical support in the development of suitable catalytic converter designs. British Leyland plans to produce its own converter hardware. Both monolithic and granular catalytic converter designs are being evaluated.

2.2.8.1.2 Problem Areas and Plans for Resolution

Durability is a problem both for the engine and the catalyst. Valve recession resulting from use of unleaded fuel has been difficult to cure, especially in the smaller engines where there is little room for valve inserts. Mechanical failure of the granular catalyst container, which results in the loss of catalyst particulates, is a problem which has not yet been solved. Another problem is catalyst poisoning due to fuel and oil contaminants. This problem is particularly difficult because the local fuel contains different amounts of sulfur and other contaminants than in the U.S. British Leyland finds it impossible to say when, or even if, a solution can be found to the problems of catalyst poisoning, attrition, or mechanical failure.

Installation of the converter has presented packaging problems because of its size and the heat generated and emitted to the local environment. In addition, expansion between the metallic case and the ceramic core of the monolithic converter design is a problem yet to be overcome. Data developed to date strongly suggest that British Leyland catalysts will have to be replaced at intermediate mileage points in order to maintain emission control for 50,000 miles.

British Leyland does not believe that any of the problems are insurmountable, but they feel they are running out of time to develop a satisfactory 50,000-mile catalytic converter.

2.2.8.1.3 Emissions

2.2.8.1.3.1 Test Programs and Vehicle Description

Tests have been carried out on the following vehicles:

Austin Marina

MGB

Triumph GT6

Triumph Spitfire

Triumph TR-6

Jaguar XJ6

The gasoline used for testing has 0.014 gm/gal of lead at 91 octane. British Leyland believes that the EPA specification for gasoline lead content will ultimately be lower than the 0.05 gm/gal value currently projected for unleaded fuel. Consequently they have not yet attempted to study the effect of higher lead content on catalyst performance.

No mention is made of test conditions, or the number of cars involved in British Leyland's test program.

2.2.8.1.3.2 Test Procedures

The 1975 Federal Test Procedures are being used for all tests. The driving cycle for mileage accumulation was not specified.

2.2.8.1.3.3 Emission Data Summary

Emission data are shown in Table 2-22 for low mileage emissions and in Table 2-23 for high mileage emissions. Some of the catalysts were identified during the EPA hearing and these are designated in the tables.

2.2.8.1.3.4 Best Emission Results

The best (low mileage) emission results were obtained with a 110-CID Austin Marina equipped with an Engelhard PTX monolithic catalyst. Emission levels

Table 2-22. British Leyland Low Mileage Emissions

Car	Engine CID	Type/ Weight, lb	Mileage	Emissions, gm/mi*			Oxidizer Catalyst	Comments
				HC	CO	NO_x		
Austin	110	**Saloon** **2500**	0	0.11	1.78	1.86	**Engelhard PTX (Pt/monolith)**	**Stacked monolith**
Austin	110	**Saloon** **2500**	0	0.04	1.49	1.67	**Engelhard PTX (Pt/monolith)**	**Stacked monolith**
			4000	0.10	0.92	2.27		
Austin	110	**Saloon** **2500**	0	0.18	2.29	2.33	**ICI noble metal/monolith**	
Austin	110	**Saloon** **2500**	0	0.19	1.38	2.08	ICI noble metal/granular	
MGB	110	Sports 3000	0	0.14	1.02	2.41	Johnson-Matthey noble metal	
Triumph GT6	113	Saloon 2500	0	0.58	1.78	2.04	Engelhard PTX (Pt/monolith)	
Triumph Spitfire	80	Sports 2000	0	0.50	1.95	1.87	Engelhard PTX (Pt/monolith)	
Triumph TR-6	152	Sports 2750	0	0.39	5.10	1.75	Engelhard PTX (Pt/monolith)	
Jaguar XJ-6	258	Saloon 4000	0	0.08	2.80	0.86	Engelhard PTX (Pt/monolith)	With EGR
			4100	0.15	3.00	1.10		
Jaguar XJ-6	258	Saloon 4000	0	0.20	2.50	1.00	Johnson-Matthey noble metal	Without EGR

*1975 CVS-CH test procedure

Table 2-23. British Leyland High Mileage Emissions

Car	Engine CID	Type/ Weight, lb	Mileage	Emissions/gm/mi*			Oxidizer Catalyst	Comments
				HC	CO	NO_x		
Austin	110	Saloon 2500	0	0.11	1.78	1.86	Engelhard PTX (Pt/monolith)	Stacked monolith
			11400	0.28	2.73	2.32		Valve recession
			11450	0.34	2.08	1.65		New head on engine
			17000	0.63	4.65	1.32		Catalyst was sent back to supplier
Austin	110	Saloon 2500	0	0.18	2.29	2.33	ICI noble metal/monolith	
			6574	0.45	3.00	1.97		
			9200	0.20	2.61	2.21		
			13000	No data provided				Test in progress
Austin	110	Saloon 2500	0	0.19	1.38	2.08	ICI noble metal/granular	
			4500	0.25	1.14	2.44		
			5800	No data provided				Slight catalyst deterioration

*1975 CVS-CH test procedure

were 0.04 gm/mi HC, 1.49 gm/mi CO, 1.67 gm/mi NO_x. After 4000 miles the emission levels were still within standards at 0.10 gm/mi, 0.92 gm/mi, and 2.27 gm/mi. Best high mileage results were achieved with the Austin vehicle also using an Engelhard PTX catalyst; 11,450 miles were accumulated with emissions still within standards at 0.34 gm/mi HC, 2.08 gm/mi CO, 1.65 gm/mi NO_x. The plotted results indicate that HC exceeded the standard at 12,000 miles. The maximum mileage accumulated on this system was 17,000 miles.

2.2.8.1.3.5 Test Data Variability

In answering questions from the Ford Motor Company, British Leyland stated that the day-to-day repeatibility of data on one car is ± 15 percent. The spread of results with mileage and on different examples of nominally identical vehicles has not yet been determined.

2.2.8.1.4 Fuel Consumption and Performance Penalties

British Leyland states that the difference between a 1975 car marketed for the U.S. and one for the home market will be a 13 percent increase in fuel consumption coupled with reduced performance of about 10 percent.

Driveability will be slightly improved compared with 1972/73 models because of the use of richer air/fuel ratios. However, driveability will be worsened during the warmup period. Expected fuel consumption for a 1975 vehicle with a 110-CID engine is 28.7 mi/gal.

2.2.8.2 Alternate Systems

2.2.8.2.1 Special Design Features

Every effort is being made to dispense with EGR on all models. The alternate system would incorporate EGR on some models, including the Jaguar. In addition, it may be necessary to add a catalyst overtemperature protection system.

2.2.8.2.2 Problem Areas and Plans for Resolution

No problems with the EGR and the catalyst by-pass system are defined.

2.2.8.2.3 Emissions

The 1975-CVS-CH Federal test procedure is used. The duty cycle for mileage accumulation was not specified. The test vehicle was a Jaguar XJ6. Emission results obtained with and without EGR are shown in Table 2-22. The maximum mileage accumulated was 4100 miles with HC = 0.15 gm/mi, CO = 3.0 gm/mi, and NO_x = 1.10 gm/mi. No information on test data variability specific to the alternate system is provided.

2.2.8.2.4 Fuel Consumption and Performance Penalties

British Leyland believes that better driveability is achieved without EGR. No further information on fuel consumption or performance is given.

2.2.9 Citroen

2.2.9.1 First-Choice System

2.2.9.1.1 Special Design Features

Citroen did not identify a candidate 1975 system (Ref. 2-18).

2.2.10 Daimler-Benz AG (Mercedes-Benz)

2.2.10.1 First-Choice System

2.2.10.1.1 Special Design Features

A first-choice 1975 emission control system is identified separately for the Mercedes-Benz vehicles equipped with a gasoline engine and for vehicles equipped with a diesel engine (Refs. 2-23, -24, -25).

2.2.10.1.1.1 Gasoline Engine

Mercedes-Benz vehicle equipped with a gasoline engine is projected to use the following subsystems in 1975:

Noble metal/monolith oxidation catalyst converter

Secondary air injection

- Exhaust gas recirculation (EGR)
- Engine modifications
  - Carburetor or fuel injection system changes
  - Retarded ignition and short choke operation
  - Reduced compression ratio (8:1)
  - Warmup of intake air

The bulk of promising low emission levels data has been obtained on dynamometer testing with Engelhard PTX-4 noble metal/monolith catalytic converters. Some good results have also been obtained with Matthey Bishop, Kali-Chemie, and Degussa catalysts.

2.2.10.1.1.2 Diesel Engine

The Mercedes-Benz vehicle equipped with a light duty 4-cylinder diesel engine of the 2.2-liter class is likely to meet the 1975 Federal emission standards for HC, CO, and NO_x. However this is contingent upon the promulgation of emission standards and test procedures applicable to diesel engine vehicles. Only minor modifications to the fuel injection system will be required provided the restrictions on exhaust smoke and particulate content are not unduly severe.

2.2.10.1.2 Problem Areas and Plans for Resolution

2.2.10.1.2.1 Gasoline Engine

According to Daimler-Benz, the success of its entire emission control system hinges on the development of a successful oxidizing catalytic converter. New catalyst formulations are tested on engine dynamometers as soon as received. The major problems with the catalytic converters are insufficient mechanical durability and high deterioration of conversion efficiency. Daimler-Benz is very pessimistic about the resolution of the catalyst deterioration problem and does not expect any technological breakthrough in this area.

2.2.10.1.2.2 Diesel Engine

Daimler-Benz states that an EPA ruling on smoke and particulate emissions from diesel engines is urgently needed. In addition, pollutant measurement techniques applicable to diesel engines must be defined.

Daimler-Benz believes it will be able to meet the 1975 Federal standards with its light duty diesel engine by simple modifications to the fuel injection system. However, it cautions that this will no longer be true if severe smoke and particulate controls are instituted. This is a particular problem during cold start. Daimler-Benz has achieved low levels of smoke and particulate emissions (less than 1 gm/mi). Further reduction might force a change in the engine combustion characteristics which could increase the other pollutant levels.

2.2.10.1.3 Emissions

2.2.10.1.3.1 Test Programs and Vehicle Description

The bulk of Daimler-Benz's test program is being run on dynamometers with engines or experimental cars. As long as 50,000-mile durability cannot be successfully completed on engine dynamometers, Daimler-Benz sees no need for committing cars to road testing. Oxidizing catalytic converters are tested on the 2.2-liter (134 CID) 4-cylinder engines used on Mercedes-Benz (MB) 220 vehicles, on the 2.8-liter, 6-cylinder engines with fuel injection used on MB 250 vehicles, and on the 4.5-liter (276 CID) V-8 engines with fuel injection used on MB 280 vehicles.

The experimental vehicles are as follows:

MB 220 V-25 (3500 lb) mechanical shift
MB 220 VL-5 (3500 lb) mechanical shift
MB 250 (3500 lb) automatic shift
MB 250 CE (3500 lb) automatic shift
MB 250 CE (4000 lb) automatic shift

MB 280 (4000 lb) automatic shift
MB 450 (4000 lb) automatic shift
MB W108 (4000 lb) automatic shift

No information is provided on the diesel test program.

2.2.10.1.3.2 Test Procedures

All emission level measurements on gasoline engines reported by Daimler-Benz were made using the 1975-CVS-CH Federal Test Procedure (Table 2-24). Diesel engine test procedures are not defined.

Catalytic converter durability tests are reported in Table 2-25. Those tests with both hours and miles shown were run on engine dynamometers using the Mercedes W3 test schedule (mild driving conditions) as follows:

Duration, hr	RPM	Load
1/4	idle	-
1/2	2000	1/2
1/2	3000	1/2
1/4	idle	-
1/4	3000	full
1/2	4000	1/3
2 1/4		

The systems in Table 2-25 with only mileage shown were road tested in an unspecified manner. The gasoline used for test contains less than 0.01 gm/gal of lead and less than 0.03 percent of sulfur.

2.2.10.1.3.3 Emission Data Summary

2.2.10.1.3.3.1 Gasoline Engines

The low mileage emission results obtained recently by Daimler-Benz are listed in Table 2-24. The majority of catalyst converters shown were manufactured by Engelhard (platinum/monolith). Sixty percent of the test

Table 2-24. Daimler-Benz Low Mileage Emissions

Test Date	Test Number	Car Model	Vehicle Mass, lb	Emissions, gm/mi* HC	CO	NO_x	Oxidizer Catalyst
12-9-71	1778	220V25	3500	0.38	3.48	0.61	Engelhard
12-10-71	1788	220V25	3500	0.25	2.04	0.72	Engelhard
12-16-71	1818	220V25	3500	0.41	8.19	0.61	Engelhard
1-31-72	2032	220VL5	3500	0.23	2.84	0.44	Engelhard
10-27-71	1579	250CE	3500	0.75	5.43	1.16	Engelhard PTX-4.4.5
10-29-71	1591	250	3500	0.24	1.85	1.69	Engelhard 2 PTX-4, PTX-5
11-3-71	1574	250CE	3500	0.30	1.57	1.84	Engelhard PTX-4.4.5
11-4-71	1611	250CE	3500	0.36	1.74	1.97	Engelhard PTX-4.4.5
11-11-71	1632	250CE	3500	0.51	1.13	1.72	Engelhard PTX-4.4.5
11-11-71	1636	250CE	3500	0.22	1.85	1.94	Engelhard PTX-4.4.5
11-12-71	1639	250CE	3500	0.35	2.09	2.15	Engelhard PTX-4.4.5
11-12-71	1640	250CE	3500	0.27	2.69	1.27	Engelhard PTX-4.4.5
11-15-71	1644	250CE	3500	0.36	2.69	2.01	Engelhard PTX-4.4.5
11-10-71	1655	250CE	3500	0.51	3.69	1.65	Engelhard PTX-4.4.5
11-10-71	1657	250CE	3500	0.45	1.83	1.55	Engelhard PTX-4.4.5
11-16-71	1679	250CE	4000	0.73	1.73	1.82	Engelhard PTX-4.4.5
11-18-71	1683	250CE	4000	0.35	3.50	2.16	Engelhard PTX-4.4.5
11-24-71	1710	250CE	4000	0.56	4.39	2.12	Engelhard PTX-4.4.5
12-8-71	1770	250CE	3500	0.36	3.06	1.82	Engelhard PTX-4.4.5
12-9-71	1780	250CE	4000	0.34	3.52	2.20	Engelhard PTX-4.4.5
12-10-71	1791	250	3500	0.30	3.04	1.89	Engelhard 2 PTX-4, PTX-5

Table 2-24. Daimler-Benz Low Mileage Emissions (Continued)

Test Date	Test Number	Car Model	Vehicle Mass, lb	Emissions, gm/mi HC	CO	NO_x	Oxidizer Catalyst
12-14-71	1805	250	3500	0.33	3.18	1.36	Engelhard 2 PTX-4, PTX-5
12-17-71	1827	250CE	4000	0.33	3.16	1.88	Engelhard PTX-4.4.5
1-24-72	1997	250CE	4000	0.31	3.99	2.97	Engelhard PTX-4.4.5
1-26-72	2015	280	4000	0.68	7.21	2.24	Engelhard PTX-4.4.5
3-6-72	2208	250CE	4000	0.33	7.66	2.95	Engelhard PTX-4.4.5
12-14-71	1807	W108	4000	0.47	3.99	1.60	Engelhard
1-4-71	1873	W108	4000	0.35	4.32	1.75	Engelhard
1-7-72	1911	450	4000	0.20	3.37	2.05	Engelhard
1-10-72	1912	450	4000	0.31	4.09	2.08	Engelhard
1-27-72	2012	W108	4000	0.40	3.62	2.34	Engelhard 4 PTX-4
1-27-72	2020	W108	4000	0.48	1.49	2.59	Engelhard 4 PTX-4
2-2-72	2028	W108	4000	0.11	3.42	1.91	Engelhard 4 PTX-4
2-3-72	2057	W108	4000	0.13	2.08	1.82	Engelhard
2-8-72	2072	W108	4000	0.17	2.41	1.70	Engelhard 4 PTX-4
2-9-72	2076	W108	4000	0.22	2.81	1.61	Engelhard 4 PTX-4
2-10-72	2079	W108	4000	0.16	1.88	1.57	Engelhard
2-11-72	2084	W108	4000	0.19	1.90	1.23	Engelhard 4 PTX-4
2-16-72	2085	W108	4000	0.12	2.35	1.19	Engelhard 4 PTX-4
2-15-72	2099	W108	4000	0.14	2.87	1.18	Engelhard 4 PTX-4
2-18-72	2110	W108	4000	0.13	2.45	1.35	Engelhard 4 PTX-4
2-25-72	2151	W108	4000	0.22	3.81	1.17	Engelhard

Table 2-24. Daimler-Benz Low Mileage Emissions (Continued)

Test Date	Test Number	Car Model	Vehicle Mass, lb	Emissions, gm/mi*			Oxidizer Catalyst
				HC	CO	NO_x	
2-29-72	2180	W108	4000	0.11	2.34	1.14	Matthey Bishop
3-3-72	2197	W108	4000	0.13	5.56	0.97	Engelhard 4 PTX-4
3-7-72	2204	W108	4000	0.10	3.17	1.44	Engelhard 4 PTX-4
3-13-72	2245	W108	4000	0.13	2.67	0.81	Matthey Bishop
3-16-72	2258	W108	4000	0.10	1.47	1.14	Matthey Bishop
3-17-72	2264	W108	4000	0.15	1.72	0.88	Matthey Bishop
-	2324	-	-	0.10	1.70	0.28	Kali-Chemie
-	2377	-	-	0.14	2.3	1.0	Degussa

*1975 CVS-CH test procedure

Table 2-25. Daimler-Benz Catalyst Durability Tests

Company	Serial No.	Hours	Miles	Status
Engelhard				
1. PTX	1212 638	330	15500	Defective
2. PTX	1212 446I	140	6600	Defective
3. PTX	1212 446F	60	2820	Defective
4. PTX	1212 564	30	1410	Defective
5. PTX	1212 425D	45	2100	Defective
6. PTX	1212 446A	4	188	Defective
7. PTX	1212 446B	50	2350	Running
8. PTX	1212 446C	50	2350	Running
9. PTX	1212 446D	50	2350	Running
10. PTX	1212 446E	55	2580	Running
11. PTX	1212 212L	(a)	1200	Running
12. PTX	1212 429B	51	2390	Running
13. PTX	1212 429C	65	3050	Running
Kali-Chemie				
14. KC	101/4035	54	2530	Defective
15. KC	103/4035	32	1500	Defective
16. KC	1/3368	18	845	Defective
17. KC	2/3368	(a)	1300	Running
18. KC	3/3368	(a)	1300	Defective
19. KC	4/3368	(a)	1300	Running
20. KC	5/3368	(a)	1300	Running
Heraeus				
21. H	101/250	17	800	Defective
22. H	102/250	12	565	Defective
23. H	101/350	23	1080	Defective
24. H	102/350	34	1600	Defective
Grace				
25. G	1	14	660	Running
Degussa				
26. DI	506E	32	1500	Defective
APC-Ceraver				
27. APC	1 RC6226	72	3380	Defective
28. APC	2 RC6226	72	3380	Defective
Matthey Bishop				
29. MI	1/3A	63	2950	Defective
30. M	8/3A	(a)	3700	Defective
31. M	9/3A	(a)	3700	Defective
32. M	10/3A	(a)	3700	Running
33. M	11/3A	(a)	3700	Running
34. M	101/350/3A	4	188	Defective

(a) = Road test

data listed are within the 1975 Federal emission standards. Vehicles and emission levels pertinent to the mileage accumulation data shown in Table 2-25 were not specified.

2.2.10.1.3.3.2 Diesel Engines

Tests of the 220D (diesel) and 220 gasoline powered Mercedes automobiles (1972 procedure) revealed that the diesel produces about 30 percent as much HC, 5 percent as much CO, and 50 percent as much NO_x as the gasoline 220. Based on PHS odor rating and opacity smokemeter measurements, it was found that under certain driving conditions the odor was "as intense as old style injector-equipped city buses." The smoke opacity rating was on the order of 10 percent.

Table 2-26 gives emission results obtained with a single car. All emission levels are within standards as measured by the 1972 CVS procedure using a heated FID instrument for the HC. Daimler-Benz stated that the diesel emission levels should not deteriorate significantly with accumulated mileage.

2.2.10.1.3.4 Best Emission Results

2.2.10.1.3.4.1 Gasoline Engine

The best (low mileage) emission results shown were obtained in Test #2324 with a Kali-Chemie catalyst: HC = 0.10 gm/mi, CO = 1.70 gm/mi, and NO_x = 0.28 gm/mi. The highest accumulated mileage shown in Table 2-25 is 15,500 miles and was obtained on an engine dynamometer with an Engelhard PTX catalyst converter. This test was terminated when some axial displacement of the substrate was noted. The type of catalyst converter which appears the most promising to date will be road tested as soon as more units are received from Engelhard Industries.

2.2.10.1.3.4.2 Diesel Engine

From Table 2-26, the best results shown are: HC = 0.26 gm/mi (CVS-continuous), CO = 1.55 gm/mi, and NO_x = 1.09 gm/mi.

Table 2-26. Mercedes 220 Diesel 1972 Federal Test Results

	Run Number and Date					
	1	2	3	4	5	
Emissions, gm/mi	5/28/71	6/1/71	6/2/71	6/3/71	6/4/71	Average
HC, SwRI FIA Heated[a]						
CVS Bag	0.25	0.26	0.31	0.25	0.36	0.29
CVS Continuous[b]	0.86	0.82	0.92	0.71	1.06	0.87
HC, Beckman FIA[c]						
CVS Bag	0.27	0.27	0.23	0.18	0.18	0.22
CVS Continuous[a]	0.28	0.38	0.30	0.26	0.23	0.29
CO, NDIR	1.62	1.61	1.60	1.55	1.73	1.62
NO (as NO) NDIR	0.47	0.59	0.47	0.46	0.39	0.47
Electrochem[d]	0.73	1.07	0.29	0.33	0.33	0.55
Chemilum[e]						0.42
NO_x (as NO_2) Saltzman	1.28	1.34	1.46	1.09	1.22	1.27
Chemilum						1.83
Formaldehyde	0.014	0.018	0.009	0.018	0.018	0.015
Aliphatic Aldehydes (as formaldehyde)	0.022	0.018	0.016	0.025	0.020	0.020
Acrolein	0.012	0.010	0.019	0.019	0.013	0.015

[a] Heated lines and analyzer at 375°F

[b] Entire 23-min run hand-integrated on 1-sec intervals.

[c] Model 400 heated analyzer at 100°F.

[d] Envirometrics Faristor.

[e] Single run made 6/14/71 with new Thermo Electron Instrument.

Note: The diesel is not covered by the 1972 Light-Duty Procedure.

2.2.10.1.3.5 Test Data Variability -- Gasoline Engines

Daimler-Benz reported that the spread of test results over the last six months using the first-choice system on MB 220 vehicles is as follows:

	HC	CO	NO_x
Spread, gm/mi	0.23 - 0.41	2.04 - 8.19	0.44 - 0.72
Spread, %	±29	±65	±24
Average, gm/mi	0.31	4.70	0.59

2.2.10.2 Alternate Systems

2.2.10.2.1 Special Design Features

If improved pellet noble metal catalysts are shown to be capable of better durability than the monolithic noble metal catalysts they will be used for the 1975 model year vehicle. Daimler Benz has not yet tested these alternate systems.

If the possibility of fire resulting from catalyst overtemperature is shown to be a real danger, a safety subsystem will be added. Daimler-Benz is developing the technology to prevent possible catalyst substrate overheating through the use of either a by-pass system or an air pump cutoff.

2.2.11 Honda Motor Co., Ltd.

2.2.11.1 First-Choice Systems

2.2.11.1.1 Special Design Features

The latest Honda information available is derived from Reference 2-18, dated October 28, 1971. As of this date, a first-choice emission control system had not yet been selected. However, the best emission results reported were obtained with a car equipped with an oxidizing catalytic converter, air injection thermal reactor (AIR), exhaust gas recirculation (EGR), and engine modifications.

2.2.11.1.2 Problem Areas and Plans for Resolution

The main problem area outlined by Honda concerns the improvement of methods for protecting systems from overtemperature conditions which severely reduce the durability of the emission control system.

2.2.11.1.3 Emissions

No details, either on test cars or on test programs are provided. Emission level measurements were made using the 1975 CVS-CH test procedure. The best values indicated were HC = 0.20 gm/mi, CO = 3.0 gm/mi, and NO_x = 0.8 gm/mi. No durability test results were provided. Test data variability is not given. An increase in pollutants by a factor of two is expected for mass-produced vehicles compared to the prototypes.

2.2.11.1.4 Fuel Consumption and Performance Penalties

The fuel consumption penalty for urban driving is expected to be as high as 25-30 percent. Performance penalties are mentioned with regard to decreased driveability caused by EGR. No data are provided.

2.2.11.2 Alternate Systems

2.2.11.2.1 Special Design Features

Removal of the thermal reactor is considered by Honda to represent an alternate system selection. The best emission levels given for this system are HC = 0.20 gm/mi, CO = 4.0 gm/mi, and NO_x = 1.2 gm/mi. No durability test data are available. The fuel consumption penalty is not as severe as for Honda's first-choice system: for urban driving it is 10-15 percent; for steady-state, 12 percent.

2.2.12 Mitsubishi Motors Corporation

2.2.12.1 First-Choice Systems

2.2.12.1.1 Special Design Features

The data on Mitsubishi are derived from the 1971 EPA technology assessment survey response data October 1971 (Ref. 2-26), which identifies the Mitsubishi first-choice emission control system as follows:

Oxidation catalyst
Air injection into the exhaust system
Exhaust gas recirculation (EGR)
Engine modifications
    Improved carburetor and fast choke
    Modified ignition system

Efforts have been made to reduce pollutants in the cylinder discharge to the lowest possible levels. Pollutant levels were reported as HC = 1.7 gm/mi, CO = 23.5 gm/mi, and NO_x = 1.43 gm/mi (1975 CVS-CH); very little margin is said to be available for further improvement.

The selection of the oxidation catalyst has not yet been made. However, it would appear from the comments provided that a noble metal/monolithic type is the preferred choice.

2.2.12.1.2 Problem Areas and Plans for Resolution

The major problem area is identified as catalyst deterioration. Variation of engine raw emissions with mileage accumulation is also a problem and so is the durability of the secondary air pump. The actual catalyst deterioration factor was reported as 3.0. It is hoped that this will be reduced to 2.0 by 1975.

2.2.12.1.3 Emissions

2.2.12.1.3.1 Test Programs and Vehicle Description

The Mitsubishi test program has involved more than 30 combinations of different catalysts and converter designs, and encompasses 50 test vehicles (the only car exported to the USA by Mitsubishi is the Dodge Colt). Whereas the noble metal/monolithic appears to be the favored choice, both the noble metal/pellet and the base metal/pellet are also being tested.

2.2.12.1.3.2 Test Procedures

The emission level measurements are made by the 1975 CVS-CH test procedure and durability testing is done using the AMA driving schedule.

2.2.12.1.3.3 Emission Data Summary

Zero mile emission levels obtained with an Engelhard PTX-5 platinum monolith catalytic converter were reported as HC = 0.3 gm/mi, CO = 3.1 gm/mi, and NO_x = 1.9 gm/mi. At 29,000 miles the emissions were quoted as HC = 0.6 gm/mi, CO = 6.0 gm/mi (NO_x not given). Data submitted by UOP at the EPA Suspension Request Hearings (Ref 2-19) from an unidentified Mitsibushi vehicle (presumed to be the Dodge Colt) show the following results:

	Emissions, gm/mi		
Mileage	HC	CO	NO_x
600	0.14	2.25	-
4243	0.19	2.91	-
7000	0.25	4.33	- (screen failure at about 8000 miles)

2.2.12.1.3.4 Test Data Variability

Mitsubishi states that its emission data show variations as high as ±50 percent. It is "compelled" to make several measurements at each test point to obtain a reliable average emission value. Mitsubishi feels that this plurality of test measurements would create a serious problem if required for all production vehicles.

2.2.12.1.4 Fuel Consumption and Performance Penalties

The fuel consumption penalty for the Mitsubishi 1975 catalyst-only system is stated by Mitsubishi to be approximately 5 percent. Engine power penalties could be as high as 20 percent. Mitsubishi comments that driveability has deteriorated, but hopes that further development will provide adequate driving characteristics by production time.

2.2.12.2 Alternate Systems

2.2.12.2.1 Special Design Features

Mitsubishi has been developing a partial (rich) thermal reactor. It could be used in addition to an oxidation catalyst in combination with rich air/fuel mixtures to improve NO_x emissions. For this combination of devices, the following emission levels were measured: HC = 0.23 gm/mi, CO = 4.5 gm/mi, and NO_x = 0.9 gm/mi. According to Mitsubishi the fuel consumption penalty for the combined system is 25 percent. No other pertinent data on alternate systems are provided.

2.2.13 Nissan (Datsun)

2.2.13.1 First-Choice Systems

2.2.13.1.1 Special Design Features

The Nissan (Datsun) first-choice system will consist of an HC/CO noble monolithic catalytic converter, EGR, air injection, and engine modifications.

A noble metal monolithic catalyst was selected for use in the first-choice system because of the excessive attrition experienced with base metal pellet type catalysts. Although efforts are continuing to evaluate catalysts from some 21 different worldwide sources, Nissan indicates (Ref. 2-27) it is currently testing Engelhard and Johnson-Matthey catalysts on its first-choice system. It was stated in Ref. 2-28 that all of the test fleet vehicles use Engelhard catalysts on a stacked substrate. This is in contradiction to the Phase II test results (Table 2-27) which show Car B-697 equipped with a UOP noble metal catalyst. Clarification is not provided in the Nissan references.

The reasons for the selection of the first-choice system were not discussed.

2.2.13.1.2 Problem Areas and Plans for Resolution

Nissan reports (Ref. 2-29) that the primary problems continue to be lack of catalyst durability and deterioration of catalyst conversion efficiency. It is proceeding with the development and evaluation of new catalysts as they become available. Nissan is working on several methods of accomplishing catalyst overtemperature protection including the use of an exhaust by-pass system, secondary air cut off, and/or precise air/fuel mixture control under differing driving conditions to reduce the overall heating load on the catalyst. Satisfactory performance, durability, and reliability of these systems have not yet been obtained.

In addition to overall catalyst durability, Nissan also reports driveability problems in terms of engine stall, hesitation on rapid acceleration, and general engine roughness due to EGR, spark retard, and quick release choke. Evaluation tests of vehicle driveability, with 12-18 percent EGR on both the first- and second-choice systems, rate driveability at 2 (poor) on a scale of 5 (excellent). By comparison, the 1972 model year 97.4-CID vehicle is rated as 4 (good).

2.2.13.1.3 Emissions

2.2.13.1.3.1 Test Programs and Vehicle Descriptions

The Nissan test program has been a two-phase effort. The main purpose of Phase I (now terminated) was to establish catalyst durability. Phase II tests, started in February 1972, are being conducted to test the entire vehicle concept for 1975.

Table 2-27. Nissan First-Choice System (Phase II Test Fleet)

Car No.	EMS	Catalyst	EGR	Date	Mileage	Emissions, gm/mi			Remarks
						HC	CO	NO_x	
B-700	Automatic quick released choke with fast warm-up device, retarded ignition and increased throttle opening	PTX-416 Engelhard-American Lava (stack type) with secondary air	18% (Intake manifold entry)	2/1/72	0	0.17	0.99	0.82	--
				2/14/72	4,000	0.28	2.4	0.71	--
				2/24/72	8,000	0.37	2.6	0.85	Adjusted idle setting; changed spark plug and breaker points
					12,000	-	-	-	Skipped
				3/21/72	16,000	0.50	3.5	0.87	--
B-696	Same as above	PTX-419 (stack type)	18%	2/19/72	0	0.23	0.45	0.73	--
				3/11/72	4,000	0.31	0.72	1.04	--
				3/23/72	8,000	0.23	1.2	0.78	Adjusted idle setting; changed spark plug and breaker points
B-697	Same as above	UOP Noble metal-pellet (2.4 liter)	18%	2/3/72	0	0.14	1.4	0.96	--
				2/26/72	4,000	0.31	1.8	0.90	--
				3/14/72	8,000	0.31	2.8	1.00	Adjusted idle setting; changed spark plug and breaker points

Notes: 1. All test results based on 1975 CVS-CH test procedure.
2. All tests are still running.

Phase I test vehicles were 1972 model year cars with 1.6-liter engines, manual chokes, and an EGR system which used air cleaner entry. The Phase I test fleet comprised 2500-lb vehicles.

Phase II test vehicles are 1975 model year concept cars with 2.0-liter engines, quick release automatic chokes, fast warm up devices, and an EGR system which uses intake manifold entry. The Phase II test fleet was reported to comprise 3000-lb vehicles representative of a special version incorporating unspecified safety components.

2.2.13.1.3.2 Test Procedures

Emission results reported by Nissan for the Phase I test fleet equipped with its first-choice systems were measured in accordance with the 1972-CVS-C test procedure. Phase II results were obtained in accordance with the 1975 CVS-CH test procedure. The driving cycle used on the mileage accumulation tests was reported as a modified AMA durability test route (Ref. 2-27).

2.2.13.1.3.3 Emission Data

Emission data reported by Nissan (Refs. 2-28 and 2-30) for the first-choice system are presented in Table 2-28 for the Phase I test vehicles. The current Phase II test program results are shown in Table 2-27. Phase I tests were terminated in September 1971, because, in the opinion of Nissan, the emission control deterioration rates were too high. Phase II tests are continuing. It will be noted that car No. B-700 exceeded the 1975 HC/CO standards between 8000 and 16,000 miles.

2.2.13.1.3.4 Best Emission Results

The best emission results reported by Nissan for the Phase II first-choice system were exhibited by car No. B-696 at zero miles. These results were 0.23 gm/mi HC, 0.45 gm/mi CO, and 0.73 gm/mi NO_x.

Table 2-28. Nissan First-Choice System (Phase I Test Fleet)

Car No.	EMS	Catalyst	EGR	Date	Mileage	Emission Data, gm/mi			Remarks
						HC	CO	NO_x	
B-415 (Car 1)	Manual choke	PTX-416 Engelhard-American Lava (stack type) with secondary air	18% (Air cleaner entry)	6/5/71	0	0.40	6.1	0.89	--
				6/25/71	4,000	0.75	6.1	1.15	Changed EGR filter
				7/20/71	8.000	0.83	7.1	1.16	Adjusted idle mixture; changed EGR filter
				8/26/71	12,000	1.05	7.6	1.14	Changed spark plugs, breaker point, and EGR filter
				9/13/71	17,000	0.95	8.7	1.13	Adjusted valve clearance; changed EGR filter
				9/27/71	20,000	1.13	8.6	1.24	Stopped the test because too high deterioration of emissions
B-263 (Car 2)	Manual choke	PTX-516 (stack type)	18%	6/4/71	0	0.661	5.7	0.87	--
				7/12/71	4,000	0.77	6.5	1.12	Changed EGR filter
				7/28/71	8,000	0.83	6.5	1.09	Changed EGR filter
				8/20/71	12,000	1.22	7.4	1.24	Changed spark plugs, breaker point, and EGR filter
				9/9/71	17,000	1.27	7.9	1.31	Adjusted valve clearance; changed EGR filter
				9/21/71	20,000	1.24	7.4	1.44	Stopped the test because of too high deterioration of emissions

Note: All test results based on 1972 CVS-C test procedure.

Table 2-28. Nissan First-Choice System (Phase I Test Fleet) (Continued)

Car No.	EMS	Catalyst	EGR	Date	Mileage	Emission Data, gm/mi			Remarks
						HC	CO	NO_x	
8D-463 (Car 3)	Manual choke	PTX-516 (Stack type)	20%	3/20/71	0	0.30	2.8	1.05	--
				4/20/71	4,000	0.30	3.0	1.08	--
				5/25/71	8,000	0.31	2.6	1.04	Charged air cleaner
				6/20/71	12,000	0.41	2.6	1.12	Adjusted idle setting; changed spark plugs
				7/20/71	16,000	0.45	2.9	0.85	Stopped the test because of its seriously poor driveability (rating of 1.5)
8D-388 (Car 4)	Manual choke	PTX-516 (Stack type)	18%	4/16/71	0	0.35	3.2	1.05	--
				6/15/71	4,000	0.44	5.7	0.75	Changed air cleaner and carburetor
				7/1/71	8,000	0.65	4.9	0.78	Stopped the test due to HC/CO emissions exceeding standards
8D-452 (Car 5)	Manual choke	PTX-416 (Stack type)	22%	5/1/71	0	0.55	2.8	1.05	--
				6/2/71	4,000	0.55	3.5	1.00	--
				6/25/71	8,000	0.58	3.4	0.74	Changed air cleaner and EGR filter
				7/25/71	12,000	0.73	2.9	0.75	Stopped the test due to HC emission exceeding standard

Note: All test results based on 1972 CVS-C test procedure.

2.2.13.1.3.5 Test Data Variability

No comment on Nissan test data variability can be made.

2.2.13.1.4 Fuel Consumption and Performance Penalties

Fuel consumption penalties for the Nissan first-choice system are reported to be 5-10 percent higher than the 1972 model year vehicle. Performance penalties were not specifically referred to other than in terms of poor driveability as discussed in Section 2.2.13.1.2. A statement was made that vehicle acceleration capability is impaired.

2.2.13.2 Alternate Systems

2.2.13.2.1 Special Design Features

The Nissan second-choice system uses a thermal reactor in addition to the HC/CO catalytic converter, EGR, air injection, and engine modifications employed in the first-choice system.

2.2.13.2.2 Problem Areas

Problems associated with the Nissan second-choice system encompass those reported for the first-choice system plus specific problems associated with the thermal reactor. Reactor core deformation and durability continues to be a problem as does the development of a satisfactory insulating material which will resist both mechanical vibration and high exhaust gas temperature. Efforts are continuing to develop an inexpensive and easily workable core material.

2.2.13.2.3 Emissions

2.2.13.2.3.1 Test Programs and Vehicle Descriptions

Test programs and vehicle descriptions for the Nissan second-choice system are the same as discussed in Section 2.2.13.1.3.1.

2.2.13.2.3.2 Test Procedures

Emission results reported by Nissan for the Phase I test fleet equipped with the second-choice system were measured in accordance with the 1972 CVS-C test procedure. Phase II results were obtained in accordance with the 1975 CVS-CH test procedure. The driving cycle used on the mileage accumulation tests was reported to be a modified AMA durability test route (Ref. 2-27).

2.2.13.2.3.3 Emission Data Summary

Emission data for Nissan's alternate system are given in Table 2-29 for both the Phase I and Phase II test results. The data were presented by Nissan only as a range of emission levels. The most notable deterioration in emission is seen to occur in the CO emissions for both the Phase I and Phase II test vehicles: Phase I vehicles show a fourfold increase in 32,000 miles while the level for Phase II vehicles doubles in 8,000 miles.

2.2.13.2.3.4 Best Emission Results

The best emission results achieved by Nissan cannot be determined from the data reported in Table 2-29.

2.2.13.2.3.5 Test Data Variability

Test data variability was not discussed by Nissan.

2.2.13.2.4 Fuel Consumption and Performance Penalties

The fuel economy for the Nissan second-choice system was stated to be 10-15 percent below the 1972 model year vehicle.

2.2.14 Renault

2.2.14.1 First-Choice Systems

2.2.14.1.1 Special Design Features

Reference 2-18 identifies two Renault emission control systems. One of these comprises an oxidizing catalytic converter, air injection and EGR; the other system utilizes a thermal reactor with air injection.

Table 2-29 Nissan Second-Choice System

Type	Emission Control Package	System Main Components	Phase I Test Fleet 1972 CVS-C					Phase 2 Test Fleet 1975 CVS-CH				
			Number of Vehicles Tested	Mileage	Emission Levels, gm/mi			Number of Vehicles Tested	Mileage	Emission Levels, gm/mi		
					HC	CO	NO_x			HC	CO	NO_x
Alternative System	AB	EMS Reactor, HC/CO Catalyst, EGR	8	0	0.13 to 0.44	2.0 to 4.1	0.59 to 0.78	1	0	0.27	1.9	0.73
			2	32,000	0.50 to 0.75	11 to 13	0.75 to 1.1	1	8,000	0.47	3.6	0.92

Notes: 1. Weight of vehicles tested: Phase 1 test vehicle, 2,500 lb; Phase 2 test vehicle, 3,000 lb.

2. The lowest emission values shown above were not obtained on a given vehicle, i.e., the lowest value of HC was not obtained in combination with the lowest value of CO or NO_x.

2.2.14.1.2 Emissions

Emission results (1975 CVS-CH) for the two control systems identified in Reference 2-18 are as follows:

	Emissions, gm/mi		
Systems	HC	CO	NO_x
AI (+ EGR) + OC	0.6	3.5	2.25
AI + TR	1.0	6.0	1.9

AI = Air injection
OC = Oxidizing catalyst
EGR = Exhaust gas recirculation
TR = Thermal reactor

No additional information on these systems was furnished.

Results of a 16,000 mile durability test of a Renault 1.7-liter R16 vehicle were reported by Engelhard (Ref. 2-13). These data cannot be identified with a particular Renault system. Test results are shown in Table 2-30.

2.2.15 Rolls-Royce Motors Limited

2.2.15.1 First-Choice Systems

2.2.15.1.1 Special Design Features

The latest information available from Rolls-Royce was submitted in response to the EPA technology assessment survey questionnaire and is dated 4 November 1971 (Ref. 2-31). The system most likely to be selected for 1975 model cars comprises an oxidation catalyst, manifold air injection, modulated EGR, and engine modifications that include a new carburetor, new choke (AED-Automatic Enrichment Device), retarded spark, and 7.5:1 compression ratio. Transmission-controlled spark and catalyst overtemperature protection devices may also be added. Catalytic converters using both noble and base metal catalysts are being investigated.

Table 2-30. Emission Data, Renault 1.7-Liter R16
(Reported by Engelhard)

Mileage	Emissions, gm/mi 1975 CVS-CH test procedure			Remarks
	HC	CO	NO_x	
0	0.08	1.01	1.46	
1,000	0.23	1.72	1.57	65 primary idle jet
1,000	0.11	1.75	1.63	70 primary idle jet
4,000	0.15	2.55	1.50	
8,000	0.31	12.57	0.86	
8,000	0.36	12.0	0.85	
8,000	0.33	11.11	1.09	New Beach air pump
8,000	0.26	6.20	1.77	Saginaw air pump fitted
8,000	0.15	2.67	1.93	Saginaw pump relief valve restricted
12,000	0.48	4.60	1.38	Before service
12,000	0.27	3.28	1.79	After service
16,000	0.33	3.31	1.50	
16,000	0.31	4.51	1.87	Check test

2.2.15.1.2 Problem Areas and Plans for Resolution

Rolls-Royce states that, due to installation problems, at least 6 feet of exhaust piping will separate the catalytic converters from the engine. A major redesign of the exhaust system could reduce the separation to 4 feet, which is the closest possible with the existing vehicle design. This remoteness results in a long warm-up time. Other major problems are durability and overheating of the catalytic converter, developing a reliable overtemperature protection system, and EGR valve plugging. No details of the continuing development effort are given. Rolls-Royce states that "only by releasing straight from the drawing board to production, with all the risks that this entails, could a catalytic converter system be incorporated in 1975 model cars."

2.2.15.1.3 Emissions

No details of Rolls-Royce's emissions test program are given. The emission data quoted are measured per the 1971 Federal test procedure. With a Johnson-Matthey platinum/monolithic catalyst, Rolls-Royce has obtained these emission levels: HC = 0.18 gm/mi, CO = 2.53 gm/mi, and NO_x = 4.15 gm/mi. No durability test data were provided. No information on test data variability was submitted.

2.2.15.1.4 Fuel Consumption and Performance Penalties

Rolls-Royce estimates that a fuel consumption penalty as high as 25 percent is possible. Driveability problems are anticipated, but the performance penalties, including those associated with the reduction of the compression ratio from 9:1 to 7.5:1 and the addition of EGR, are not given.

2.2.15.2 Alternate Systems

2.2.15.2.1 Special Design Features

Alternate designs of exhaust manifolds and carburetors are being pursued. To improve mixture preparation and distribution so that extremely lean mixtures may be used, an auxiliary small bore induction manifold with extreme exhaust heating is being investigated. Rolls-Royce states that the system appears promising.

2.2.16 Saab

2.2.16.1 First-Choice System

2.2.16.1.1 Special Design Features

The final selection of a first-choice system has not yet been made by Saab. However, according to testimony presented in Reference 2-32, Saab currently favors its Concept 2 system as a possible first choice. This system consists of the following:

a. Zenith CD2 carburetor
b. Noble metal, monolithic catalyst
c. Air injection

The selection of a specific catalytic converter has not yet been made. Exhaust gas recirculation does not appear to be necessary to meet the 1975 Federal standards for NO_x. No overtemperature protection device/system has been tested to date, although Saab feels that such a system must be developed to adequately control emission levels.

2.2.16.1.2 Problem Areas and Plans for Resolution

The most significant problem encountered by Saab has been the lack of durability of the catalyst. Deactivation of the catalyst has been caused both by lead poisoning and by overheating due to over-rich mixtures during cold start and retarded spark timing. Mechanical cracking of the monolithic catalyst support has also been experienced due to what Saab believes is improper design of the container. The design does not provide sufficient allowance for the differences in expansion between the container and the substrate.

Development of a satisfactory catalytic converter is continuing. Saab is continuing work in-house on container design and development as well as working with outside vendors. It has ordered but has not yet received the Matthey Bishop catalyst on the Corning extruded substrate.

2.2.16.1.3 Emissions

2.2.16.1.3.1 Test Programs and Vehicle Description

Saab is currently conducting durability tests on the first-choice system over the Saab MAR (Mileage Accumulation Route) driving cycle, which is its EPA-approved vehicle certification driving cycle (Ref. 2-32).

Saab has conducted two tests to date on its first-choice system (see Table 2-31). The first test (Test No. 4) utilized an oval Matthey Bishop noble metal catalyst and was terminated after 995 miles when inspection revealed that the catalyst insert was loose. The unit was returned to the manufacturer. The second test (Test 5) was conducted on the same car equipped with a Matthey Bishop catalyst of different but undefined configuration (Ref. 2-33).

2.2.16.1.3.2 Test Procedures

All test data reported by Saab are based on the 1975 CVS-CH test procedure.

Table 2-31. Low Mileage Emission Data -- Saab First-Choice System

Test No.	Car No.	Engine	Catalyst Mileage	Emissions, gm/mi		
				HC	CO	NO_x
4	311	2 liter	0	0.30	1.73	2.23
			995	0.21	1.95	2.00
5	311		0	0.21	2.32	1.95
			1200	0.21	1.76	2.02
			2520	0.32	4.67	1.75
			3540	0.12	1.27	1.07

2.2.16.1.3.3 Emission Data Summary

Results of two Saab low mileage tests of their first-choice system are shown in Table 2-31. As previously indicated, Test 4 was terminated at 995 miles; Test 5 is continuing. To date, approximately 3500 miles have been accumulated on this vehicle.

When questioned about the high CO results at 2520 miles in Test 5, Saab indicated (Ref. 2-32) that no adjustments were made to the vehicle between the 2520 and 3540 mile test points and that they knew of no reason for this other than test-to-test variation.

No high mileage emission data were reported for the first-choice system.

2.2.16.1.3.4 Best Emission Results

The best (low mileage) emission results reported by Saab for its first-choice system were obtained on Test 5, Car 311 at 3540 miles. These were 0.12 gm/mi HC, 1.27 gm/mi CO, and 1.07 gm/mi NO_x.

2.2.16.1.3.5 Test Data Variability

Reference 2-33 provides the following general comment on test data variability: Saab does not believe that the lack of reproducibility in the test results is caused by the test procedure. No other comment is provided.

2.2.16.1.4 Fuel Consumption and Performance Penalties

Fuel consumption penalties are not delineated by Saab. Only a general statement is made (Ref. 2-33) that fuel consumption will be increased due to richer air/fuel ratio, reduced spark advance, and lower compression ratio. Fuel consumption for Tests 4 and 5 conducted on the first-choice system was reported to be 22 mi/gal; no baseline fuel consumption value was reported.

A 6 percent power loss was reported for Tests 4 and 5 with driveability rated at 7 on a scale of 10. A driveability rating of 5 is defined by Saab as borderline; a rating of 6 and higher is classified as acceptable.

2.2.16.2 Alternate Systems

2.2.16.2.1 Special Design Features

The Saab second-choice system, denoted as the Concept 3 system, will consist of the following:

a. Bosch electronic fuel injection or Zenith CD-2 carburetor
b. Base metal pellet catalyst (Saab container)
c. Air injection
d. EGR (may be deleted)

Selection of a specific base metal pelletized catalytic converter has not yet been made, although Saab has stated that its best results to date with the base metal catalyst have been obtained with catalysts from Kalie-Chemie and Monsanto. A final decision has not been made with regard to the use of EGR, although Saab expressed the opinion that it would not be necessary to meet the 1975 standards.

Other systems being studied by Saab include the Concept 1 and Concept 4 systems. The Concept 1 system incorporates electronic fuel injection or a Zenith carburetor, noble metal/monolithic catalyst (Engelhard), and on-off EGR (may be deleted). Three tests have been conducted on this system; the mileage accumulated was 1770, 4550 and 7700 miles. All three tests were terminated when the catalyst insert came loose.

The Saab Concept 4 system, consisting of a Zenith CD2 carburetor, on-off EGR, and a base metal pellet catalyst (vendor-supplied container) is currently undergoing test. To date, 4180 miles have been accrued, with emission levels of 0.39 gm/mi HC, 4.55 gm/mi CO, and 1.53 gm/mi NO_x.

In addition to the preceding, several systems which include a thermal reactor are being investigated. In general, these thermal reactor systems have not been effective and are being investigated only as a back-up system in the event adequate durability cannot be obtained with a catalytic converter system. Saab has not tested a thermal reactor/catalytic converter system (Ref. 2-32).

2.2.16.2.2 Problem Areas and Plans for Resolution

In addition to the general problem of catalyst durability discussed in Section 2.2.16.1.2, Saab reports that catalyst attrition and loss of particulate presents a serious problem associated with the base metal catalyst. Catalyst poisoning with 4 ppm of phosphorous in the fuel was also experienced in Test 12 on a car equipped with a Degussa catalyst.

2.2.16.2.3 Emissions

2.2.16.2.3.1 Test Programs and Vehicle Description

A total of six tests have been reported by Saab on vehicles equipped with its second-choice system. Of these, four (Tests 6, 7, 9, and 12) are or have been run over the Saab MAR driving cycle, one (Test 8) is being conducted over a "stop-and-go" driving cycle which consists of mixed city driving with frequent cold starts, and one (Test 10) is being tested over the Saab normal road driving cycle which is run 16 hours a day at an average speed of 44 mph and a maximum of 70 mph.

Test vehicles used for testing the Saab second-choice system include those equipped with both 1.85- and 2.0-liter engines, both automatic and manual transmissions, and base metal, pellet-type catalysts from three different manufacturers. Particular combinations employed are indicated together with the emission results in Table 2-32.

2.2.16.2.3.2 Test Procedures

All test results were obtained in accordance with the 1975 CVS-CH test procedure.

2.2.16.2.3.3 Emission Data

Low and high mileage emission results for the Saab second-choice system tests are shown in Table 2-32.

Table 2-32. Emission Data--Saab Second-Choice System

Test No.	Car No.	Engine Liters	Fuel System	Catalyst Mfr	Mileage	Emissions, gm/mi HC	CO	NO_x	Remarks
6	301	1.85	EFI	Kali-Chemie	0	0.23	2.98	2.59	MAR driving cycle
					2,410	2.18	4.72	2.55	
					4,010	0.26	2.76	2.56	
					5,350	0.32	3.38	2.66	
					7,430	0.58	6.20	2.33	
					7,460	0.50	6.12	2.38	Test continuing
7	301	1.85	EFI	Kali-Chemie	0	1.26	29.63	0.77	High CO unexplained; MAR cycle
					13	0.22	2.85	1.02	
					208	0.17	1.83	1.21	
					450	0.25	3.01	1.29	
					515	0.25	3.21	1.38	
					960	0.19	2.24	1.30	
					1,410	0.20	1.90	0.00	NO_x unexplained
					2,170	0.19	2.18	2.89	
					2,770	0.31	2.79	1.52	
					4,310	0.27	3.41	1.53	
					5,930	0.25	3.63	1.96	
					7,360	0.33	3.93	0.00	NO_x unexplained; test terminated as container cracked
8	314	2.0	Carb.	Monsanto	0	0.26	3.03	1.10	With EGR; stop-and-go driving cycle
					60	0.16	2.39	0.87	
					110	0.27	2.15	1.56	
					160	0.20	2.68	1.32	Test continuing

Table 2-32. Emission Data--Saab Second-Choice System (Continued)

Test No.	Car No.	Engine Liters	Fuel System	Catalyst Mfr	Mileage	Emissions, gm/mi			Remarks
						HC	CO	NO_x	
9	385	1.85	EFI	Monsanto	0	0.07	0.34	1.52	MAR driving cycle
					43	0.10	0.75	1.10	
					185	0.18	0.93	1.54	
					195	0.22	1.75	1.99	
					208	0.21	1.57	2.14	
					592	0.24	1.18	2.07	
					764	0.22	1.44	2.37	
					2,740	0.22	1.33	2.54	
					4,210	0.23	1.18	2.59	
					6,380	0.19	1.40	2.10	
					8,280	0.29	1.34	2.14	
					10,420	0.50	2.97	2.87	Test continuing
10	341	2.0	EFI	Monsanto	0	0.31	1.61	1.75	Normal driving cycle
					2,170	1.09	8.89	1.31	
					2,190	0.61	4.16	1.58	
					2,300	0.79	6.81	1.49	Test continuing
12	301	1.85	EFI	Degussa	0	0.19	2.11	1.66	MAR driving cycle
					20	0.21	0.95	1.75	
					615	0.37	5.44	2.01	
					630	0.32	5.81	1.81	
					1,000	0.16	6.22	2.00	
					2,600	0.74	15.66	2.52	
					2,600	1.64	30.72	3.09	Test terminated; catalyst poisoned by 4ppm phosphorous

2.2.16.2.3.4 Best Emission Results

The best low mileage emission levels reported by Saab for its second-choice system without EGR were on Test 9 at zero miles. This vehicle was equipped with a 1.85-liter engine, electronic fuel injection, secondary air injection, and a Monsanto base metal catalyst. Emission levels achieved were 0.07 gm/mi HC, 0.34 gm/mi CO, and 1.52 gm/mi NO_x.

Only one vehicle has been tested using the Saab second-choice system with EGR. This vehicle (Test 8) was equipped with a 2.0-liter engine, a Zenith carburetor, a Monsanto base metal catalyst, and metered EGR (rate not specified). The best emission results achieved, at 60 miles, were 0.16 gm/mi HC, 2.39 gm/mi CO, and 0.87 gm/mi NO_x.

2.2.16.2.3.5 Test Data Variability

Test data variability is not discussed by Saab other than the general comment reported in Section 2.2.16.1.3.5.

2.2.16.2.4 Fuel Consumption and Performance Penalties

Fuel consumption penalties were not reported by Saab for its second-choice system tests. Actual fuel consumptions ranged from 21 mi/gal on Test 6 to 25 mi/gal on Test 9. Fuel consumption was not checked on Test 8 (the vehicle included EGR). Baseline fuel consumption was not reported.

A power loss of 5 percent was reported for all second-choice system tests with the exception of Test 12; in this test a power loss of 3 percent was reported.

Driveability was reported to have a rating of 5 (borderline) on the EGR-equipped car used in Test 8, a rating of 6 on Tests 9 and 10, and a rating of 8 on Tests 6 and 7.

2.2.17 Toyo Kogyo

2.2.17.1 First-Choice Systems

2.2.17.1.1 Special Design Features

The system proposed by Toyo Kogyo for use on the rotary engine for model year 1975 is currently planned to consist of a thermal reactor, improved control of the secondary air injection system, and an improved induction system. No EGR is planned for use on the rotary engine for 1975. Toyo Kogyo also indicates (Ref. 2-34) that a forced cooling system would be used on the reactor for the rotary engine vehicle. This statement was not amplified further during the Toyo Kogyo testimony.

A first-choice system has not yet been selected by Toyo Kogyo for the 4-cylinder reciprocating piston engine. Development work is continuing on three different systems for this engine. These include the thermal reactor system, the HC/CO catalytic converter system, and a combination of the two. No other details of these developmental systems were provided by Toyo Kogyo, although it could be inferred from its testimony (Ref. 2-34) that EGR will not be used on the 1975 model year reciprocating engine but rather is being investigated on test bed engines for possible application to the 1976 model year reciprocating engine emission control system.

2.2.17.1.2 Problem Areas and Plans for Resolution

The primary problem associated with the Toyo Kogyo rotary engine emission control system is that the durability of the reactor has not yet been demonstrated. Because of the increased reactivity required to meet the 1975 standards, the device is expected to operate at a core temperature approximately 130°F higher than the 1972 production model. The possible adverse effects on underhood components of the vehicle caused by the increased temperature are currently being investigated to determine whether it will be necessary to make any modifications to the vehicle body structure or underhood components.

With regard to the reciprocating engine systems, the major problem encountered with the catalytic converter systems has been lack of adequate durability. Details of the durability problem were not provided, nor were the type or design of catalytic devices identified. Unsatisfactory results were reported in efforts to devise a satisfactory catalyst overtemperature protection system.

The thermal reactor device applied to the reciprocating engine has created the usual problem of excessive heat in the engine compartment and, in addition, has created difficulties in compartment packaging. These problems might require major modifications to the vehicle body structure and to the layout of engine components.

2.2.17.1.3 Emissions

2.2.17.1.3.1 Test Programs and Vehicle Description

The rotary engine test fleet consists of three 2750-lb vehicles equipped with 70-CID two-rotor rotary engines and manual transmission. Only low mileage emission tests have been conducted. The reciprocating engine test vehicle is equipped with a 110-CID engine. The test fleet consists of three vehicles equipped with the thermal reactor system, two equipped with the catalytic converter system, and three equipped with the thermal reactor/catalytic converter system. Emission tests of the reciprocating engine systems have also been limited to low mileage.

Durability tests (50,000 miles) are scheduled to start in May, 1972 and be completed in September, 1972 for both the rotary and reciprocating engine vehicles. The driving cycle to be followed was specified (Ref. 2-35) only as "general durability testing of the vehicle-system combination on the road and dynamometer to obtain the final design of the control system."

2.2.17.1.3.2 Test Procedures

All emission test data reported by Toyo Kogyo were obtained in accordance with the 1975-CVS-CH test procedure.

2.2.17.1.3.3 Emission Data Summary

Emission levels achieved at low mileage on the rotary engine equipped with a thermal reactor were 0.17 gm/mi HC, 2.2 gm/mi CO, and 0.93 gm/mi NO_x. These values represent the average of 18 tests obtained from three vehicles, each of which had accumulated from 300 to 1000 miles. Individual test results were not reported.

Low mileage emission results for the conventional engine with each of three emission control systems are shown in Table 2-33. All results represent the average emissions obtained from the indicated number of vehicles and individual tests as reported by Toyo Kogyo. All tests were conducted on a 110-CID engine. As was the case for the rotary engine vehicles, individual test results were not reported.

2.2.17.1.3.4 Best Emission Results

Best overall emission results were achieved with the rotary engine as reported above. For the reciprocating engine, the best results were achieved with the thermal reactor-only system, which yielded average values of 0.15 gm/mi HC, 2.6 gm/mi CO, and 2.3 gm/mi NO_x, as shown in Table 2-33.

2.2.17.1.3.5 Test Data Variability

Test data variability was reported by Toyo Kogyo (Ref. 2-35) in terms of a 1 sigma standard deviation for each engine/emission control system. This has been converted to the coefficient of variation, $\sigma/\bar{x}$, %, for ease of comparison with data variability presented by other manufacturers, as shown in the following table.

Table 2-33. Toyo Kogyo Reciprocating Engine Emission Results

Control System	No. of Vehicles Tested	No. of Tests Averaged	Emissions, gm/mi, CVS-CH			Mileage When Tested
			HC	CO	NO_x	
Thermal Reactor (Type A)*	2	6	0.15	2.6	2.3	300 - 1100
HC/CO Catalyst (Type X)*	2	6	0.29	2.8	2.6	400 - 500
Thermal Reactor (Type B)* plus Catalyst (Type Y)*	3	9	0.25	2.9	2.5	500 - 600

*Not otherwise identified

Toyo Kogyo Test Data Variability
(Coefficient of Variation, $\sigma/\bar{x}$)

			Coefficient of Variation, $\sigma/\bar{x}$,%		
Engine	Control System	No. of Tests	HC	CO	NO_x
Rotary	Thermal Reactor	18	17.6	10.9	8.6
Recipr.	Thermal Reactor	6	16.7	11.5	6.1
Recipr.	Catalytic Converter	66	13.8	8.9	8.1
Recipr.	Reactor plus Converter		12.0	9.7	7.6

2.2.17.1.4 Fuel Consumption and Performance Penalties

The fuel consumption penalty for the rotary engine was reported by Toyo Kogyo to be 5 percent below the 1972 model year vehicle which is also equipped with a thermal reactor. The reported 5 percent loss in fuel economy is due to (unspecified) changes in the air/fuel ratio (Ref. 2-35). Driveability of the 1975 rotary engine vehicle is rated by Toyo Kogyo as "fair," as is the 1972 model year vehicle.

The fuel consumption penalties are reported for the reciprocating engine emission control system as 10 percent for the thermal reactor system and 5 percent for both the catalyst and reactor/catalyst systems when compared to the 1972 model year production vehicle. Driveability is rated as "fair" for all three emission control systems.

2.2.17.2 Alternate Systems

No second-choice system is planned by Toyo Kogyo for use on the 1975 rotary engine vehicle. At the present time, it plans to continue with the reactor core fabricated from 20-percent chrome, 3-percent aluminum sheet metal stock. They did indicate, however, that they might have to go to a reactor core material with some nickel content if the results of the durability tests so indicate.

None of the previously described emission control systems being developed by Toyo Kogyo has been designated as a second-choice system and will not be reviewed in this section.

2.2.18 Toyota

2.2.18.1 First-Choice Systems

2.2.18.1.1 Special Design Features

The Toyota first-choice system, designated System 75-A, comprises an oxidizing catalytic converter, air injection, EGR, and engine modifications (Refs. 2-36, 2-37). The catalytic converter is a pelletized noble metal design utilizing palladium as the catalyst agent (the source of the catalyst materials was not specified; Toyota plans to develop and manufacture its own container). The engine modifications include redesign of the induction system to improve warm-up characteristics (low thermal inertia intake manifold), carburetor improvements, and lean choke operation. Toyota also is investigating a possible change in combustion chamber configuration to reduce HC and NO_x emissions.

Toyota states that the selection of System 75-A was based on the following considerations:

a. The catalytic converter was essential to the goal of meeting Federal emission standards for 1975.

b. EGR looked promising as a means of achieving the California 1974/75 NO_x standards, and was in an advanced state of development.

c. The engine modifications selected were based on improvements under development and in use for a number of model years.

The selection of palladium for the catalyst was a cost consideration (palladium is one-third the price of platinum). The pelletized configuratic⁻ was selected in preference to a monolith structure partly because Toyota believed the monolithic version tended to be poisoned by lead easier than the larger volume pelletized design.

2.2.18.1.2 Problem Areas and Plans for Resolution

In general, the performance and durability of the 75-A system are unsatisfactory. Low mileage emission results meet the 1975 standards but fail to meet Toyota's low mileage engineering goals. The possibility of improving catalyst warm-up characteristics by mounting the converter closer to the engine is under consideration; however, this poses a potential problem of converter overheating.

With regard to other system problems, Toyota is still working to achieve and maintain an optimum air/fuel ratio which would permit both the catalyst and EGR system to operate at best efficiency.

Component problems in the Toyota system include catalyst durability, converter case deformation and rupture, and carburetor icing and throttle valve freezing in cold weather due to EGR (the Toyota system introduces recirculated gas between the carburetor venturi and throttle valve). Although no data were available to support this claim, Toyota feels that 0.05 gm/gal lead content gasoline will be unsatisfactory; some toxification of the catalyst is suspected even with the 0.02 gm/gal gasoline that currently is being used in the test vehicles. High fuel consumption and degraded performance were additional problems associated with the first-choice system.

With regard to the air/fuel problem, Toyota plans to make carburetor improvements, including the addition of altitude compensating devices. It also is considering the use of fuel injection.

With regard to catalyst system durability, Toyota is working on the development of a stronger catalyst carrier and is studying new designs for the structure and suspension of the case. Monolithic systems are also being investigated.

The EGR problems are being approached in several directions, including coating the throttle shaft with a special protective material, controlling EGR gas temperature, and terminating the recirculating flow at a minimum engine temperature.

2.2.18.1.3 Emissions

2.2.18.1.3.1 Test Programs and Vehicle Description

Toyota's testing of its complete emissions package is limited. Only one vehicle durability run of the first-choice 75-A system has been made. One more first-choice vehicle test was started recently. The test vehicle is equipped with a 96.9-CID, 4-cylinder engine and an automatic transmission. The vehicle has an inertia wheel rating of 2500 lb.

2.2.18.1.3.2 Test Procedures

Durability mileage accumulation was accomplished using the prescribed EPA driving cycle and emission tests were conducted using the CVS method. It was not specified that 1975-CVS-CH procedures were used. The test program deviated from nonstandard practice in that maintenance was performed at each 4000-mile test interval (the maintenance was described as "engine adjustments"; no further description was provided).

2.2.18.1.3.3 Emission Data Summary

Data from the single durability test of the first-choice system are shown in Table 2-34. Toyota's low mileage emission goals of 0.19, 1.5, and 1.9 gm/mi, respectively, for HC, CO, and NO_x are exceeded for the HC and CO pollutants at zero miles. Two entries are shown for each 4000-mile test point. These are the emission results obtained before and after conducting the maintenance mentioned above. At or near the 12,000-mile point it was observed that the converter case had broken and that the catalyst was scattered. The test was then terminated.

Table 2-34. Toyota First-Choice System Durability Test Emission Results

Emission Control System	Mileage	1975 CVS-CH Emissions, gm/mi		
		HC	CO	NO_x
75-A	0	0.21	2.60	1.16
	4,000	0.39	2.67	1.30
		0.29*	2.13*	1.36*
	8,000	0.51	2.56	1.47
		0.27*	2.82*	1.29*
	12,000	0.46	4.13	1.39
		0.36*	2.55*	1.25*

*Engine adjusted.

Note: Catalytic converter damage found at 12,000 mi.

2.2.18.1.3.4 Best Emission Results

Best results are represented by the data shown at zero miles; that is, 0.21 gm/mi HC, 2.60 gm/mi CO and 1.16 gm/mi NO_x.

2.2.18.1.3.5 Test Data Variability

Toyota states that tests of its prototype 1975 emission package vehicles showed variations in HC, CO, and NO_x emissions of 50, 30, and 30 percent, respectively, about the mean values.

2.2.18.1.4 Fuel Consumption and Performance Penalties

When operated over the driving schedule of the 1975 Federal test procedure, the 75-A system showed an increase in fuel consumption of 10 percent.

The following performance problems were observed in the driveability test vehicles: power loss of 10-20 percent, torque loss at lower engine speeds of 20-50 percent, engine overheating, run-on, difficulty in hot restarting, tip-in, rough idle, engine stalling, surging, hesitation, back-fire, poor acceleration (especially with EGR operation), and vibration.

2.2.18.2 Alternate Systems

2.2.18.2.1 Special Design Features

Toyota does not have an alternate system for the 1975 model year. Two other systems are currently under development. These systems, designated 76-A and 76-B, appear to be targeted toward the 1976 model year application. The 76-A system incorporates engine modifications, EGR, an oxidizing catalyst, and a reducing catalyst. The 76-B system contains the same components as the 76-A and, in addition, incorporates a thermal reactor.

Durability test results for these systems are limited; the data presented show that neither system met the 1976 standards at zero miles. Both systems failed the 1975 CO standard at relatively low mileage: 76-A at or before 4000 miles and 76-B at or before 8000 miles. Additional information on these systems may be found in Reference 2-37.

2.2.19 Volkswagen

2.2.19.1 First-Choice System

2.2.19.1.1 Special Design Features

Using the building-block approach, Volkswagen is developing its 1975 system so as to permit the add-on of a reducing catalyst (or catalyst bed) for the 1976 model year vehicle (Refs. 2-38, 2-39, 2-40, 2-41). Two first-choice 1975 systems are identified. Both use a thermal reactor, an HC/CO converter, and EGR. One system employs carburetion, the other employs "conventional EFI (Electronic Fuel Injection)."

The thermal reactor serves principally as a warm-up device for the catalytic converter. The opposed-piston Volkswagen engine poses special problems in this regard because two reactors are required in order to effect a close engine mounting arrangement. The catalytic converter is a monolithic type (the Johnson-Mathey AC-8 noble metal design is preferred). A ceramic monolithic substrate manufactured by American Lava is used.

In addition to the above systems which are designed for the opposed-piston air-cooled engines, Volkswagen delineated another first-choice system which is designed for the water-cooled in-line engine used in the Audi vehicle. This emission system basically comprises an HC/CO converter with EGR.

A component/feature description for each of the systems discussed above is provided in Table 2-35.

Table 2-35. Volkswagen First-Choice Systems Description

Air-Cooled Engine (VW)		Water-Cooled Engine (Audi)
Concept 1 (EFI)	Concept 2 (Carburetion)	Concept 4
EFI	Modified Carburetor	Modified Carburetor
EGR[a]	EGR[b]	EGR[b]
Air Injection[c]	Air Injection[c]	Air Injection[d]
Thermal Reactor	Thermal Reactor	Extreme Spark Retard during warm-up.
Catalytic Converter (HC/CO)	Catalytic Converter (HC/CO)	Catalytic Converter (HC/CO)
Converter Overtemperature Diverter System	Converter Overtemperature Diverter System	Converter Overtemperature Diverter System
Low Thermal Inertia Exhaust Manifold	Low Thermal Inertia Exhaust Manifold	Low Thermal Inertia Exhaust Manifold

[a] Upstream throttle entry, effective after warm-up

[b] Upstream carburetor entry at low load, downstream at high load; effective after warm-up

[c] Into exhaust ports and thermal reactor on warm-up; thereafter into thermal reactor only

[d] Into exhaust ports on warm-up; thereafter into HC/CO converter

2.2.19.1.2 Problem Areas and Plans for Resolution

The problems discussed by Volkswagen include the following: (1) increased fuel consumption, (2) decreased engine performance, (3) mechanical stability of the catalyst support monolith, (4) potential of fire due to the high temperature operation of the converter, and (5) maintaining emission control system adjustment. In addition to these problems, Volkswagen identifies major design problems in the following areas: (1) sealing and lubricating the exhaust by-pass valve; (2) EFI system performance; (3) carburetor air/fuel balance; and (4) mechanical durability, reactivity loss, and start-off performance deficiencies in the catalytic converter.

Volkswagen sees no possibility of improving the fuel consumption behavior of the control system in the foreseeable future. Some improvement in driveability might be achieved by substituting "special reactor devices" (not further identified) for the currently used lean choke operation. The performance loss problem is stated to be intractable except by the device of increasing engine displacement or mean effective cylinder pressure. Both of these solutions would require a major engine redesign.

2.2.19.1.3 Emissions

2.2.19.1.3.1 Test Programs and Vehicle Description

Volkswagen asserts that it has conducted 250 emission tests in the course of developing and improving Volkswagen control systems. These tests were performed exclusively on low mileage vehicles using air-cooled engines with displacements of 1.6 and 1.7 liters and water-cooled engines of 1.6 liter displacement. While Volkswagen has operated durability test cars and has accumulated 15,000 kilometers on at least one of its first choice systems, this program is being conducted solely for the purpose of evaluating mechanical durability and has not been interrupted to measure emissions.

2.2.19.1.3.2 Test Procedures

Volkswagen (low mileage) emission results were obtained using 1975 test procedures.

2.2.19.1.3.3 Emission Data Summary

Low mileage emission data for the Volkswagen first-choice emission systems are shown in Table 2-36. The data represent mean values for several tests of different vehicles having less than 600 miles accumulated. Included in the emissions package reflected by the data is a NO_x reducing catalyst. Volkswagen's basic plan is to delete the reducing catalyst for the 1975 system if sufficient NO_x control can be achieved by other means.

2.2.19.1.3.4 Best Emission Results

The best overall emission results for each of the Volkswagen first-choice systems are included in Table 2-36. It may be seen that the air-cooled engine does considerably better in CO control with the Volkswagen thermal reactor included in the system. Concept 4 (water-cooled engine without thermal reactor) appears to accomplish satisfactory CO control by the warm-up extreme-spark-retard technique. The best data for both engine types are exemplified by the following emission values for Concept 1: HC = 0.25, CO = 2.2, and NO_x = 0.39 gm/mi.

2.2.19.1.3.5 Test Data Variability

Data needed to evaluate variability were not provided.

2.2.19.1.4 Fuel Consumption and Performance Penalties

The emission control systems which Volkswagen has under development for meeting 1975 standards increase fuel consumption by at least 20 percent over 1974 models, decrease engine performance by 10 to 25 percent, and adversely affect driveability by causing hesitation during acceleration and cruise, particularly if the engine is operated at lower than normal temperature. The loss of performance is stated to be the direct consequence of modifying the

Table 2-36. Low Mileage Emission Data Summary--Volkswagen First-Choice Systems (with NO_x Converter)

Concept No. and (Engine)	Emissions, gm/mi (Mean)			No. of Vehicles	No. of Tests	Emissions, gm/mi (Overall Best Value)			Test Procedure	Remarks
	HC	CO	NO_x			HC	CO	NO_x		
1 (Air Cooled)	0.38	2.2	0.64	3	10	0.25	2.2	0.39	1975-CVS-CH	With NO_x converter
1 (Air Cooled)	0.46	5.54	0.5	3	6	0.49	4.78	0.42	1975-CVS-CH	With NO_x converter, without thermal reactor
2 (Air Cooled)	0.49	4.9	0.46	1	9	0.39	2.8	0.46	1975-CVS-CH	With NO_x converter
4 (Water Cooled)	0.82	4.04	0.57	4	10	0.62	3.35	0.29	1972-CVS-C	

combustion process to reduce emissions. Volkswagen provides little hope for overcoming these difficulties without a major redesign of the engine.

2.2.19.2 Alternate Systems

2.2.19.2.1 Special Design Features

The Volkswagen alternate 1975 system comprises an advanced EFI (Electronic Fuel Injection) device, EGR, a low thermal inertia exhaust manifold, an HC/CO oxidation catalyst, and a catalyst overtemperature protection system. Few details concerning this alternate system were provided in the Volkswagen submittal or testimony transcript. Ten tests (1975 CVS-CH) of a single (air-cooled engine) vehicle equipped with this system, including the NO_x catalyst bed, yielded the following results:

	Emissions, gm/mi		
Values	HC	CO	NO_x
Mean Value	0.35	1.36	0.31
Best Overall Value	0.20	2.01	0.11

2.2.20 Volvo

2.2.20.1 First-Choice Features

2.2.20.1.1 Special Design Features

The Volvo first choice system comprises the following subsystems (Refs. 2-42, -43, -44, -45):

Catalytic converter (platinum/monolithic)
Secondary air supply
Catalyst protection warning system
Exhaust gas recirculation
Engine modifications
Fuel injection system
Modified intake system

Both Engelhard and Johnson-Mathey platinum catalytic converter designs are being evaluated for use in this system. The fuel injection system is being developed by Bosch, Germany, and features a feedback device which senses the quantity of exhaust gas recirculated to the engine intake.

Volvo has worked with thermal reactors and catalytic converters since early 1970. Its selection of a monolithic, noble metal catalytic converter for the first-choice system is stated to be based on a number of considerations including the following: (1) emission results (low mileage) met engineering standards, (2) fuel economy and driveability were favorable compared to other systems, (3) installation and attrition problems were minimized, (4) mechanical failures were reduced, and (5) the device offered the best possibility for incorporation into a complete emissions package which could meet the 1975 standards.

2.2.20.1.2 Problem Areas and Plans for Resolution

Like other automobile manufacturers experimenting with catalyst systems, Volvo has been unable to demonstrate satisfactory durability of the catalytic converter and has experienced problems in catalyst attrition, mechanical failure overheating, noise, and rapid deterioration in conversion efficiency. According to Volvo, the last problem is due in part to the use of 0.05 gm/gal lead content fuel. More recent testing has been accomplished with 0.015 gm/gal fuel which appears to provide better performance with mileage accumulation.

Maximum mileage achieved with the Volvo first-choice system was accomplished with an Engelhard PTX 416 converter which, according to testimony presented at the Volvo recall hearing on April 24, 1972, failed at 29,000 miles (see Table 2-37). By way of attacking the durability problem, Volvo has ordered and intends to test other Engelhard PTX converter designs. One type has a layered, as opposed to a rolled, substrate structure. Another

Table 2-37. Volvo First-Choice System--High Mileage Emissions

Test No.	Car Reg. No.	Mileage[a] at test	% Excess Fuel[b]	Emissions, gm/mi[c]			Catalytic Converter	Remarks
				CO	HC	NO_x		
601	OB 46234 (Volvo 144, engine B20F, automatic transmission)	0	0	2.17	0.21	1.31	Engelhard PTX-416 (Spiral Wound)	With EGR
641		1,600	↓	1.33	0.28	1.60		
679		3,864		0.94	0.27	2.35		
715		5,815		0.91	0.31	1.79		
756		8,138		6.14	0.48	1.76		
766		9,370		9.55	0.45	1.59		Engine problems
851	OB 44085 (Volvo 144 engine B20F)	9,415		2.08	0.18	1.82	Converter from car OB 46234	With EGR EGR valve changed.
941		14,283		0.88	0.18	2.07		
1020		18,221		1.34	0.46	1.78		
1073		22,875		2.67	0.51	2.18		
1080		22,900		4.33	0.35	2.05		d
1086		22,950		3.70	0.20	1.76		
1091		25,344		2.45	0.24	1.82		
		29,900						Failure

[a] Total mileage accumulated on catalytic converter

[b] Referenced to an unspecified nominal setting

[c] All tests use 1975 CVS-CH procedure

[d] Fuel injection nozzle changed (poor driveability)

type with the layered structure uses a new improved catalyst coating. Ten of these new designs will be installed in durability test cars; others will be used in low mileage cars for testing different aspects of the first-choice emission system operation.

2.2.20.1.3 Emissions

2.2.20.1.3.1 Test Programs and Vehicle Description

Durability testing of the Volvo system has been conducted primarily on a subsystem basis; complete system vehicle testing had just been started as of the date of the Suspension Request Hearing.

The vehicle test program to date has been performed with Volvo vehicle models 142 and 144 fitted with engine-type B20F (4-cylinder engine with electronically controlled fuel injection).

The test fleet consists of about 15 cars fitted with emission control systems in various development and engineering phases. Both Engelhard and Johnson-Mathey noble metal monolithic catalytic converter systems are being tested for the first-choice system; other catalysts (including AC-Delco, UOP, and Grace base metal types) are being tested on a second-choice basis.

Wherever low mileage results are promising, the Volvo testing procedure is to continue to accumulate mileage on those vehicles and systems that display good performance. The high mileage test fleet, therefore, comprises those vehicles that have demonstrated good, low mileage test performance.

2.2.20.1.3.2 Test Procedures

The 1975 Federal test procedure (three-bag cold/hot start technique) is being used in the test program. The driving cycle for mileage accumulation was not specified.

Table 2-38. Volvo First-Choice Emission System--Low Mileage Emissions

Test No.	Car Reg. No.	Mileage at test	% Excess -Fuel[a]	Emissions, gm/mi[b]			Catalytic Converters	Remarks
				CO	HC	NO_x		
433	OB 46234 (Volvo 144 engine B20F automatic transmission)	0	0	2.18	0.12	2.12	Engelhard PTX-416 (Spiral Substrate)	Without EGR Automatic transmission Same reactor unit
508		205	0	1.04	0.15	3.23		
542		600	0	1.33	0.29	3.82		
445		25	-4	1.60	0.03	2.64		
468		160	-4	0.66	0.10	2.83		
499		185	-4	0.61	0.19	3.44		
520	OB 46232 (Volvo 144 engine B20F manual transmission)	0	0	1.92	0.43	2.60	Engelhard PTX-416 (spiral Substrate)	Without EGR Manual transmission Same reactor unit
550		155	0	1.59	0.15	3.07		
524		12	-4	1.12	0.26	2.81		
549		146	-4	1.49	0.26	3.24		
628		855	-4	0.89	0.22	3.24		
680		1,410	-4	0.60	0.27	2.22		
711		1,790	-4	0.85	0.32	2.20		
757		2,030	-0	1.59	0.28	2.90		
776		2,610	-4	1.54	0.58	2.23		
467	OB 44448	100	-4.5	1.56	0.19	3.32	Johnson-Matthey AEC 3	Without EGR Automatic transmission
475		200	-6	1.16	0.14	2.87		
		1300	-6	4.28	0.72	3.65		

[a] With reference to an unspecified nominal setting

[b] All tests with 1975 CVS-CH test procedure

[c] 100% catalyst attrition at next test.

Range of Emission Results, gm/mi

HC	CO	NO_x
0.03 - 0.43	0.60 - 2.18	2.12 - 3.82

The high mileage data on the first-choice system does not permit a statement concerning variability to be made.

Tests carried out on the same car and with the same test equipment are reported by Volvo to produce results which vary up to about 50 percent above and below the mean value.

2.2.20.1.4 Fuel Consumption and Performance Penalties

Volvo states that the increased backpressure created by the catalytic reactor, along with the power loss due to the air pump, reduces engine performance. The sum of these losses is stated to be about 10 percent for the Engelhard converter on engine type B20E and accounts for a fuel consumption increase of about 20 percent.

2.2.20.2 Alternate Systems

2.2.20.2.1 Special Design Features

The Volvo second- and third-choice systems differ from the first-choice system only in the design of the catalytic converter. Instead of the noble metal monolithic device used in the first-choice system, the second- and third-choice systems utilize base metal pelletized converters. The second-choice system employs a UOP "mini" reactor which mounts directly to the engine exhaust manifold. The third-choice system employs floor-mounted base metal catalysts of UOP and AC-Delco design.

The Volvo fourth-choice system comprises a thermal reactor, EGR, and a rapid warm-up device. This system is described in further detail in Section 6, Thermal Reactors. The discussion that follows addresses the Volvo second- and third-choice catalytic converter systems.

2.2.20.2.2 Problem Areas and Plans for Resolution

The general problem of attrition, performance deterioration, converter overheating, noise, and heat emission to the local environment as discussed in connection with the first-choice monolithic system appear also to apply to Volvo's base metal catalyst systems. Vibrations from pulsations in the exhaust and from second-order inertia forces in the 4-cylinder engine have resulted in severe attrition and breakdown of the UOP mini systems. Three of these converter units are reported to have failed.

Presumably, additional testing of the base metal catalytic converter systems will be conducted. Specific solutions applicable to second- and third-choice system problems are not discussed in the Volvo submittal.

2.2.20.2.3 Emissions

2.2.20.2.3.1 Test Programs and Vehicle Description

As described in the discussion of Volvo's first-choice system, the vehicle test program to date has been performed with Volvo vehicle models 142 and 144 fitted with engine type B20F (4-cylinder engine with electronically controlled fuel injection). The total test fleet consists of about 15 cars fitted with emission control devices in various stages of development.

2.2.20.2.3.2 Test Procedure

The 1975 CVS-CH Federal test procedure is used. The duty cycle for mileage accumulation was not specified.

2.2.20.2.3.3 Emission Data Summary

Emission results achieved on low mileage cars for the second-choice close-coupled UOP "mini" converter, along with low mileage results for the third-choice, floor-mounted AC-Delco system, are shown in Table 2-39. One high mileage test has been performed with the second-choice UOP system. The results from this test are shown in Table 2-40.

Table 2-39. Volvo Alternate Systems--Low Mileage Emissions

Test No.	Car Reg.	Mileage at test	% Excess Fuel[a]	Emissions, gm/mi[b]			Catalytic Converter	Remarks
				CO	HC	NO_x		
200	OA 34293	125	0	1.23	0.11	2.20	UOP	Without EGR
215		210	0	1.10	0.14	2.39	UOP	
247		275	0	2.10	0.25	2.29	UOP	
269		350	0	1.19	0.13	2.29	UOP	
273		375	0	1.62	0.12	2.15	UOP	
479	OA 34293	1,630	-9.5	1.24	0.23	1.16	UOP	With EGR (second-choice system)
489		1,650	-2.5	2.72	0.28	1.64	UOP	
498		1,690	-8	2.64	0.40	1.73	UOP	
516		1,720	-7	2.49	0.30	1.60	UOP	
525		1,760	-7	2.60	0.36	1.72	UOP	
528		1,800	-9.5	1.16	0.21	1.68	UOP	
	OB 44448	130	0	2.74	0.36	3.70	AC-Delco	Without EGR
732	OB 50430	120	0	2.43	0.24	3.14	AC-Delco (new pellet type)	

[a] Referenced to an unspecified nominal setting

[b] 1975 CVS-CH test procedure

Table 2-40. Volvo Alternate Systems--High Mileage Emissions

Test No.	Car Reg.	Mileage at test	% Excess Fuel[a]	Emissions, gm/mi[b]			Catalytic Converter	Remarks
				CO	HC	NO_x		
602	OB 44085 Automatic transmission	0	-8	1.69	0.12	1.24	UOP ↓	With EGR (second-choice system)
647		1,600	-8	0.66	0.24	1.58		
692		4,093	-5	0.56	0.47	1.76		
733		5,852	-5	6.24	0.18	1.26		
		7,000						Reactor breakdown

[a] Referenced to an unspecified nominal setting

[b] 1975 CVS-CH test procedure

2.2.20.2.3.4 Best Emission Results

The Table 2-39 data show that the second-choice (UOP) system was well within the limits of the 1975 standards at 1800 miles, with emission levels of 0.21, 1.16, and 1.68 gm/mi for HC, CO, and NO_x, respectively. The maximum mileage accumulated on this system was 7000 miles, at which point reactor breakdown occurred (see Table 2-40). The CO standard was exceeded at a mileage between about 4000 and 5800 miles.

2.2.20.2.3.5 Test Data Variability

The variability of the data is typified by the Table 2-39 results for the second-choice system (with EGR). In the mileage range shown, that is, from 1630 to 1800 miles, the data vary about the mean by 42 percent for HC and 85 percent for CO.

2.2.20.2.4 Fuel Consumption and Performance Penalties

These performance parameters are not discussed for the second- and third-choice Volvo systems.

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3. ENGINE MODIFICATIONS

3.1 BACKGROUND

With the establishment of the California automobile emission regulations in 1966, and the recognition that more stringent standards would probably evolve, the automobile manufacturers initiated major development efforts directed toward significantly reducing engine exhaust emission levels. These efforts are typified by such programs as the Improved Combustion System (IMCO) by Ford, the Controlled Combustion System (CCS) by General Motors, the Cleaner Air System (CAS) by Chrysler, and by other supporting activities such as the Inter Industry Emission Control (IIEC) program involving six major petroleum manufacturers and five automobile manufacturers.

The above efforts, in conjunction with other research projects, have addressed the more than 100 vehicle characteristics or components that affect exhaust emission levels and have resulted in a large number of modifications to the basic engine and its components. These include major refinements in the ignition and carburetion systems, changes in the combustion chamber design, changes in the compression ratio and valve timing, and changes in the exhaust manifold including the addition of air injection.

As a result of all the modifications that have been applied to the 1972 automobiles, or those scheduled for inclusion in the 1973 models, exhaust emission levels have been substantially improved. HC and CO emissions have been reduced by approximately 80 percent and NO_x emissions by approximately 40 percent compared to those from uncontrolled automobiles prior to 1966. (Although the potential is available for making improvements in NO_x emissions that are similar, but smaller, to those for HC/CO, the performance penalty that would be incurred in meeting even lower standards has prevented this potential from being realized.)

Presented in Table 3-1 are the average emission levels obtained from American Motors (Ref. 3-1) certification tests and Ford (Ref. 3-2) development fleet tests. Included for comparison are the typical emissions from pre-1966 automobiles.

Table 3-1. American Motors Certification Data and Ford Development Fleet Data

Emission	Pre-1966 Uncontrolled*	Ford 1972*	Ford 1973**	Amer. Motors 1972**	Amer. Motors 1973**	Reduction Average, %
HC	17	2.37	2.09	2.45	1.51	87
CO	125	24.2	17.15	22.4	14.9	84
NO_x	5	2.22	2.42	2.83	2.78	48

*1972 CVS-C Procedure

**1975 CVS-CH Procedure

While still further improvement in emission levels might be achieved by additional modifications to the basic engine it is not reasonable to expect that these gains would be very significant.

3.2 MODIFICATION REQUIREMENTS FOR 1975

In the past, emission improvements by basic engine modifications have kept pace with the evolution of new and more severe standards, but the situation for 1975 is significantly different. Emission level standards can no longer be satisfied by improving the basic engine; compliance requires the addition of aftertreatment devices. Further, the engine and any engine modifications required for compatibility with the 1975 system must also be compatible with the components of a system which is capable of meeting the 1976 standards.

The oxidation catalyst, generally accepted as necessary to meet the 1975 HC and CO standards, imposes new requirements on basic engine emissions as well as engine performance in order to ensure satisfactory system emission levels and, at the same time, provide acceptable driveability, economy, durability, and safety. These new requirements result from limitations in the catalyst warm-up time period, the conversion capability, and the temperature tolerances of the catalyst. The EGR system, although previously incorporated to meet 1973-74 NO_x standards, imposes additional new requirements which also relate to the basic engine emissions and performance. These new EGR requirements result both from 1975 system interactions and the projection of increased EGR flow rates and/or inclusion of a reducing catalyst to meet the 1976 standards.

The EGR system and the oxidation catalyst primarily impact the carburetion and ignition systems and impose demanding requirements with respect to their response, precision, flexibility and control. Since the existing carburetion and ignition systems have already been refined to their practical limits, it is obvious that new types of these systems, with their associated sensors and controls, are needed for any advanced emission control system. All of the major automobile manufacturers are actively pursuing such new systems. Undoubtedly, the new designs also will improve the basic engine exhaust emissions; however, these designs have not been finalized and, therefore, it is not possible to predict the level of improvement that might be achieved.

Other engine modifications may be required on the 1975 emission control systems, but no automobile manufacturers have identified any which might significantly influence emissions or performance of the basic engine.

3.3 CARBURETION SYSTEM MODIFICATIONS

3.3.1 General

Carburetion systems of the conventional type in current production are, for the most part, incompatible with the emission control systems proposed for meeting the 1975 standards for the following major reasons:

a. To satisfy the condition for satisfactory emission control and acceptable vehicle performance requires a significant improvement in the preparation and distribution of the air/fuel mixture.

b. To minimize emissions during the cold start period, before the catalyst is sufficiently active, improvements are required in the predictability and response of the choke system. In addition, induction system improvements are required to promote early fuel evaporation in order to reduce the period of choke operation consistent with acceptable driveability.

c. To protect the durability of the catalytic converter and to maximize its conversion efficiency, improvements are required in the precision and response of the fuel metering system to optimize the air/fuel mixture for the complete range of operating modes and ambient conditions.

d. To provide the best balance between fuel economy, driveability and power, improvements are required in the flexibility of the fuel metering system. In addition, improvements are required to provide for controllability to optimize the integration of variable ignition timing and EGR flow rates.

Achieving such a combination of all required improvements by modifying existing designs is recognized to be impractical. Although a new type of carburetion system is a major change requiring extensive development, it is apparent that most of the automobile manufacturers are actively pursuing this approach. Their motivation is primarily to obtain a competitive advantage, for it is in this area that the technology is indeed well understood. This technology can be exploited to offset the degradation in driveability, performance, and economy that would otherwise occur in 1975 vehicles.

Because of the competitive advantage aspect, detailed progress in the development of new carburetion systems is most likely regarded as classified information: therefore, progress reported by the automobile manufacturers is probably general by intent and should be viewed accordingly.

3.3.2 Industry Status

All of the automobile manufacturers are actively engaged in some type of development program to achieve a carburetion system that will provide satisfactory performance and compatibility with their 1975 emission control systems. These programs range from the improvement of the quality control of existing carburetors to the development of completely new carburetion systems of the conventional fuel metering (venturi) or timed fuel injection types. Since these involve concurrent development of alternate systems, most of the automobile manufacturers have not committed a particular design for inclusion in their 1975 systems. This is particularily true for the foreign automobile manufacturers. As a result, the industry status in this area is presented only for the American automobile manufacturers and is based on the material provided in References 3-3 through 3-7.

3.3.2.1 American Motors

To improve carburetor performance for its 1975 emission control system, American Motors has applied refinements to the conventional carburetor including altitude compensation, ambient temperature compensation, staged power enrichment, an improved accelerator pump, and a modulated exhaust gas recirculation system. In addition, the control of carburetor fuel flow characteristics has been improved and the allowable fuel flow band tolerance has been reduced.

The requirement for improved choke performance is recognized by American Motors and a number of choke features are being investigated. These include a staged choke pull down, choke plate offset, electrically heated chokes with ambient temperature compensation, and a thermostatically controlled choke heat by-pass system. Although the exact choke requirements have not been defined, American Motors states that new choke designs, unknown at this time, will be required for their 1975-76 emission control system.

Currently, no in-house development programs for fuel injection systems are underway at American Motors; however, the Bendix fuel injection system developments are being monitored.

3.3.2.2 Chrysler

To provide better fuel metering, Chrysler is developing a number of carburetor modifications, including modulated power valves, altitude compensation, and improved lean mixture preparation.

An electrically assisted choke is a part of the Chrysler 1975 emission control system. This type of choke was developed and has been released for incorporation in 1973 models and is currently being improved for application in 1975 vehicles.

An electronic fuel metering system is under development at Chrysler. The fuel injected is controlled by direct measurement of the air and fuel flows by use of pulse-generating flow meters. Effects of intake air temperature and barometric pressure are compensated for by electronic circuits. The fuel flow control unit is operated by the metering electronics to provide programmed air/fuel ratios. This system would be compatible with the Chrysler electronic engine control, which would then combine the ignition timing and fuel metering functions. Development of this system has not progressed to a point where it can be programmed for any specific Chrysler model year vehicles.

3.3.2.3 Ford

A new concept carburetor system has been designed and development has progressed to the production engineering phase. This new system, which employes a variable venturi concept, is planned for limited application in some 1974 models and is targeted for inclusion in all 1975 emission control systems. The salient features of this new design include the following:

a. Reduced metering system complexity and reduced number of manufacturing variables that affect the carburetor-to-carburetor statistical variation.
b. Improved hot fuel handling capabilities.
c. Elimination of the "off-idle to main system" transfer problem.
d. Improved metering stability and air/fuel mixture preparation.
e. Effective altitude compensation and cold enrichment.

Development of a predictable choke system is continuing at Ford. The current "best system" features an electrically heated bimetal control which has the potential to eliminate the dependence of the current choke system on manifold vacuum for rapid release. In addition, a totally electronically programmable choke system which uses a thermister sensor and servometer activators for increased precision is also being investigated. These devices are currently being screened prior to incorporation into Ford's new carburetor system.

Ford is also pursuing the development of an electronic fuel injection system. A number of major problems have been uncovered during the development program which require resolution before this type of system can be committed to production.

3.3.2.4 General Motors

Three types of major conventional carburetors are planned as a part of the General Motors basic 1975 emission control systems. These carburetors include a modified one-barrel, a new plain tube two-stage progressive two-barrel, and a modified four-barrel. A new type of air valve carburetor, in place of the new but conventional two-barrel carburetor, is also being considered. Current plans are to continue with the present four-barrel carburetor and improve it to achieve optimum overall emission control system performance. These modifications include altitude compensation, improved choke operation, improved metering accuracy, and revised evaporation control provisions.

General Motors considers that its present choke system is marginal and does not have the potential for the improvement required to satisfy the 1975 emission control system requirements. A new system is being developed and durability testing is in progress. An electronic fuel injection system is also under development. To date, the performance of this system is not significantly better than that of the General Motors conventional carburetor systems and a number of areas require resolution before it could seriously be considered for production.

3.3.2.5 International Harvester

International Harvester, in conjunction with its supplier, is planning to make improvements in the carburetion system to be included in its 1975-76 emission control system. The progress of International Harvester's development program, however, has been compromised by the unavailability of test-specimens of advanced carburetor designs from its suppliers.

3.4 IGNITION SYSTEM MODIFICATIONS

3.4.1 General

The emission control systems proposed for 1975 require a high degree of precision. reliability and flexibility of the ignition system to ensure satisfactory emission levels and acceptable vehicle performance and driveability.

To promote early catalyst warm-up during a cold start and to optimize driveability, performance, and economy within the constraints of NO_x control by EGR requires modifications to the existing ignition systems to provide a flexible and programmable spark timing control. In addition, the durability of the catalyst requires high ignition reliability since it is intolerant to the high temperatures resulting from plug misfire or incomplete ignition.

The breaker point type of ignition systems in current production have inherent limitations which preclude complete satisfaction of the requirements for the 1975 emission systems. Further, these systems are not compatible with projected requirements for the sensing and control of the engine variables.

Consequently, most of the automobile manufacturers are actively pursuing the development of electronic ignition systems. This type of system not only has the potential for the required precision reliability and control flexibility but also provides a higher and more constant voltage output which would minimize misfiring under certain engine operating conditions. In addition, it eliminates the maintenance requirements associated with breaker point systems.

3.4.2 Industry Status

All of the American automobile manufacturers are considering the use of electronic ignition systems of the breakerless type as a part of their 1975-76 emission control systems. While some of the foreign automobile manufacturers are also considering a change to electronic ignition systems, others are not convinced of its necessity or benefits. Since the information available from the foreign manufacturers on their ignition system development programs or plans is very meager and inconclusive, the industry status is presented for the American manufacturers only, and is based on the material provided in References 3-1 through 3-5.

3.4.2.1 American Motors

Ignition systems of the breakerless inductor type and unitized designs are being investigated by American Motors to obtain improved ignition reliability, reduced maintenance, and extended useful life. To date, each of two systems has been operated over 5,000 vehicle miles and several additional installations in vehicles are planned. Incorporation of this type of system is targeted for 1975-76 vehicles.

3.4.2.2 Chrysler

Chrysler Corporation has developed an electronic ignition system which is now available on most 1972 vehicle/engine combinations. This is a breakerless inductive system in which ignition coil current is switched by an electronic control unit in response to timing signals produced by a distributor magnetic pickup. To achieve more accurate and flexible control of spark timing at all engine operating conditions an improved version of this system is being developed and is planned as a part of Chrysler's 1975 emission control system.

In conjunction with the above type of ignition system, Chrysler also proposes an electronic engine control system for its 1975 vehicles. This control system combines the operating logic of several systems into one control unit. Input signals are received from the electronic distributor, ambient temperature sensor, engine coolant, carburetor spark port, and catalyst temperature sensor. The desired spark advance is computed as a function of engine speed and load, operating temperatures, and in response to certain transient conditions. In addition, the unit shuts off exhaust gas recirculation for some operating modes, controls the catalyst by-pass protection system, and provides warning if malfunction causes the catalyst temperature to exceed 1600 °F.

3.4.2.3 Ford

Improved ignition systems have been under investigation by Ford for a number of years and this has resulted in the design and preliminary testing of an electronic ignition system which includes a breakerless type distributor. Test results have been encouraging and major system components have successfully undergone extreme stress testing without failure. In addition, a 20 percent improvement in available spark voltage during cold start cranking has been obtained. This system also provides increased spark voltage to improve ignition system performance, and indirectly, to reduce exhaust emission levels.

Current efforts are aimed at confirming initial reliability test results, completing production cost studies, and determining effects on the emission performance of normally maintained vehicles. Additional studies are being conducted to explore the use of new magnetic materials and components.

Two systems currently under study are a Ferrosonant capacitor discharge ignition system and a pulse RF ignition system. Investigations are also underway to explore the effect of various spark plug parameters with the objective of improving the misfire limit at leaner air/fuel ratios.

If its engineering development programs are successful, and if the potential advantages of this type of system are substantiated by subsequent tests, Ford plans to incorporate an electronic ignition system of the breakerless type in future emission control systems.

3.4.2.4 General Motors

General Motors is continuing the development of optimum centrifugal and vacuum spark calibration and on-off spark timing controls such as those currently used in production vehicles. An improved electronic ignition system is also being developed. This system is similar to those currently available on some models of the 1972 Pontiacs, except that it will have a higher capacity to allow a wider spark plug gap and a long-duration spark for improved ignition of lean mixtures. Currently, this improved system is in the experimental design stage.

Current plans are to phase in the new high-energy electronic ignition system for full production in the 1975 model year.

3.4.2.5 International Harvester

International Harvester is considering the inclusion of an electronic ignition system as a part of its future emission control systems. Development in this area, however, is lagging because of the lack of experimental hardware from its suppliers. The earliest date anticipated for production is 1976.

REFERENCES

3-1 American Motors Corporation, Letter to Mr. William D. Ruchekshaus, Administrator, Environmental Protection Agency, 4 April 1972.

3-2 Ford Motor Company, Technical Data Submittal provided by Ford at the request of the EPA Suspension Request Hearing Panel, 26 April 1972.

3-3 American Motors Corporation, "Emission Control for 1975-76 Model Years - Light-Duty Vehicles," Status Report, October 16, 1971.

3-4 Chrysler Corporation, "Progress Report to the Environmental Protection Agency on the Technical Effort Aimed at Compliance with 1975-76 Emission Standards, Established by the Clean Air Act of December 1970," 20 October 1971.

3-5. Ford Motor Company, "1975/1976 Light-Duty Vehicle Emission Control Program," Status Report to the EPA, October 18, 1971.

3-6 General Motors Corporation, "1975-76 Emission Control System Status," 11 November 1971.

3-7 International Harvester Company, "Summary of Efforts Directed Towards Compliance with Clean Air Act as Pertaining to Automotive Emission," November 1971.

4. EXHAUST GAS RECIRCULATION

4.1 BACKGROUND

The amount of NO_x produced by internal combustion engines is related to the combustion temperature in the cylinder. At the high combustion temperatures associated with optimum engine performance, the uncontrolled NO_x emissions are typically in the range of 4-6 gm/mi. Within the limitations of acceptable driveability and fuel economy, this quantity can be reduced appreciably by the introduction of an inert gas into the combustion chamber to absorb heat and thereby lower the temperature during combustion. Since the engine exhaust is a convenient source for an inert gas, systems employing exhaust gas recirculation (EGR) are generally proposed for the reduction of NO_x emissions to the 2-3 gm/mi level.

The lower combustion temperature resulting from the use of EGR causes a reduction in power output (at the same spark advance setting) which effectively translates into a fuel economy loss. A fuel consumption penalty of 3 to 5 percent is typical of the loss incurred for the EGR flow rates needed to reduce the NO_x emission to the 3.0 gm/mi level required by the 1973-74 and 1975 Federal standards.

EGR also effects vehicle driveability. Concurrent with the reduction in combustion temperature is a loss in pressure, a delay in the initiation of combustion and a decrease in flame speed resulting in a retarded pressure peak. The net effect is a more pronounced cycle-to-cycle pressure (and torque) variation which affects the smoothness of operation and/or response ("driveability"). Other noticeable performance effects can be rough idle, stumble during part-throttle operation, surge at certain cruise speeds, and an increase in full throttle acceleration time. In general, all of these effects increase in severity with an increase in EGR flow rate.

While all of the EGR systems operate on the same basic principle, the desings of the different manufacturers differ in a number of details. These include the location of the exhaust gas pick up, the amount of exhaust gas cooling, the point of introduction of the recycled gas into the engine induction system, the metering devices, and the modulation signal source and associated control system. Operational variables include recycle rates and "on-off" programming of EGR to achieve the required emission levels and to accommodate certain engine operating conditions.

4.2 REQUIREMENTS FOR 1975

The Federal NO_x requirements for 1975 are essentially unchanged from those of 1973-74 (3.1 versus 3.0 gm/mi, respectively). The difference, simply reflects the change in the 1975 test procedures which apply a weighted average of the hot and cold start emissions. Consequently, most of the automobile manufacturers plan to continue the production of their current types of EGR system designs at least through 1975.

To ensure satisfactory performance of the emission control system proposed for 1975, it is expected that major changes will be made in the carburetion and ignition systems and their associated controls. These systems significantly affect the basic engine characteristics and thus interact, in a complex fashion, with the emission control systems. These anticipated changes, therefore, might well affect the EGR system performance and/or requirements.

Improved carburetion and ignition systems are being developed by most of the automobile manufacturers, but production versions are not yet available. As a result, the 1975 emission control system development tests, for the most part, have been conducted with carburetion and ignition systems currently in production. The results from these tests, therefore, cannot be extrapolated to accurately predict the performance of the 1975 EGR-equipped production systems when all of the engine modifications are included.

In general, the type of carburetion and ignition system improvements that are expected should benefit the EGR system. These benefits could be in the form of improved fuel economy or driveability, which accrue through reduction of EGR flow rate requirements, or of improved NO_x emissions at the EGR flow rates currently employed by some manufacturers. Additional development, however, will be required to achieve the optimum balance in the projected 1975 emission control systems.

4.3 INDUSTRY STATUS

At the present time, the 1973 model year vehicles, most of which incorporate EGR systems, are undergoing or have completed emission control certification. A common problem that has been experienced during these tests is the limited durability of the EGR systems. This problem is associated with the plugging of orifices in the system and/or sticking of the EGR flow control valves.

To alleviate this problem, periodic EGR system maintenance during the 1973 certification tests has been allowed (References 4-1 and 4-2).

The clarification of the allowable maintenance that can be performed on the EGR system during certification tests will undoubtedly require modifications to the current EGR system designs of many of the automobile manufacturers. However, there is no information available at this time to indicate the extent of the modifications that are being considered.

REFERENCES

4-1 Aerospace Corporation Report No. TOR-0172(2787)-2, "An Assessment of the Effects of Lead Additives in Gasoline on Emission Control Systems which Might Be Used to Meet the 1975-76 Motor Vehicle Emission Standards," 15 November 1971.

4-2 Letter from E. O. Stork, Director, Mobile Source Pollution Control, to Dr. F. W. Bowditch, General Motors Engineering Staff, November 19, 1971.

4-3 Letter from E. O. Stork, Director, Mobile Source Pollution Control, to Dr. F. W. Bowditch, General Motors Engineering Staff, December 9, 1971.

5. OXIDATION CATALYSTS

5.1 SUMMARY DISCUSSION

Emission control systems incorporating catalytic converters containing an oxidation catalyst are, with one exception (Toyo Kogyo with thermal reactor), considered by the automotive industry as the "best" or "first-line" approach for meeting the 1975 Federal HC and CO emission standards for light-duty spark ignition IC engine vehicles. Despite intensive experimental evaluation programs, no one has yet demonstrated that he can meet the 1975 50,000-mile emission standards. However, one or more catalyst changes at lower mileage could permit the manufacturers to meet the 1975 standards.

The problem of meeting the HC and CO standards for a duration of 50,000-mile distance is a severe one when viewed from considerations of the inherent characteristics of oxidation catalysts. The alumina substrate or ceramic substrate with alumina wash coat which supports the active catalytic material requires a high degree of thermal and mechanical protection to guard against loss of alumina porosity (essential for high catalytic activity) and against failure of the ceramic substrate. The catalysts also are very sensitive to contamination from sources which can reduce or destroy catalytic activity (e.g., "poisons" such as lead, phosphorus, sulfur, etc.). Despite such inherent characteristics, several oxidation catalysts have been developed which merit consideration for integration into 1975-type emission control systems.

Table 5-1 summarizes typical best emission levels obtained with oxidation catalysts at low mileage, where the effects of excessive temperature or contamination have not yet significantly impaired catalyst performance. Catalysts from 13 different companies are included; the experimental vehicle systems range from conventional passenger cars to laboratory prototype 1975 systems. As can be noted, many catalysts (base metal or noble metal, pellet or monolithic) achieve HC and CO levels far below 1975 standards when

Table 5-1. Summary of "Representative-Best" Mileage Catalyst D[illegible]

				System Description							1975 CVS-CH Emissions, gm/mi			
Catalyst Mfr./Type	Testing Co.	Test/Car No.	Car and/or CID	AI	EGR	Mod. Carb.	EFE	TR	Catalyst	Test Mileage	HC	CO	NO_x	Remarks
APCC (Houdry) (Base/Pellets)	Chrysler	259	360	x	x	x		30% Size	1057 JX8-2X1	0	0.23^a	3.6^a	1.21^a	
	GM	62505 61318	Pontiac 455 Chevrolet 350	x x	x x	x x	x		1259JX3-1X1 1259JX3-1X1	6 0	0.20/ 0.25	0.8/ 2.9	1.4 1.9	
Am. Cyanamid (Base/Pellets)	No Data													
Chemico (Base/Pellets)	EPA (Ann Arbor)		1971 Oldsmobile-350						Two beds		0.15	1.36	0.26	
Engelhard (Noble/Mono)	Engelhard		351-V8	x					PTX-433	500	0.16	0.52	--	Lead Sterile fuel and ashless lube oil
			351-V8	x	x				Std. PTX-5	380	0.32	2.1	<3.0	Lead Sterile fuel and ashless lube oil
			351-V8	x	x				Imp. PTX-5	0	0.22	0.28	<3.0	Lead Sterile fuel and ashless lube oil
	Chrysler	21/119	440	x	x				0.2% Pt; Oval; 135 $in.^3$	1268	0.23	1.0	1.28	
		35/258	GD57E41/360	x	x				0.35% Pt; Oval	627	0.23	0.9	5.44	EGR off
	Volvo	913/ OB 54821	Model 144; Engine B20B	x	x				PTX-416	0	0.11	1.55	2.48	
	Am. Motors	D00-24	232-6	x					PTX-423-S	0	0.06^b	1.5^b	0.75^b	1970 type slow choke
	GM	61319	Chevrolet 350	x	x	x			PTX-4	0	0.13	1.9	1.3	
	Brit. Leyland		Austin Marina, 110 CID	x					PTX (stacked)	0	0.04	1.49	1.67	
	SAAB	3/271	1.85 Liter	x	x					0	0.43	2.99	0.96	
	Ford		351 Ford-1, Group I	x	x	x			(2) PTX-5.35	0	0.19	1.91	2.34	Riverside program
			351 Ford-1, Group III	x	x	x			(2) PTX-5.35, 1 PTX-7.35	0	0.17	1.77	2.26	Riverside program
		1A58-D	1971 351 W-2V	x	x	x		Type H	PTX-5.35 (RH) PTX-5.10 (LH)	0	0.23^a	3.11^a	1.27^a	Cold emissions } Ford 1975 Durability Test Program
										0	0.10^a	1.41^a	0.99^a	Hot emissions }

[a] 1972 CVS-C test procedure

[b] Least-squares straight line value

Table 5-1. (Continued)

Catalyst Mfr./Type	Testing Co.	Test/Car No.	Car and/or CID	System Description						Test Mileage	1975 CVS-CH Emissions, gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst		HC	CO	NO_x	
W.R. Grace (Base/Pellets)	W.R. Grace	275	1970 Impala-350	x					Davex-142 (300 in.^{3})		0.17	3.24		
	GM	2823	Buick-455	x	x				Davex 142 (SMP 7-3881)	0	0.20	4.7	2.9	
		1246	Cadillac-500	x	x	x			Davex 117	0	0.27	1.7	2.9	
W.R. Grace (Noble/Mono)	W.R. Grace	300	1971 Chevelle-350	x					Davex 502 (51 in.^{3})		0.21	1.70		
	Chrysler	2/117	360	x	x			30% Size	Davex 47V (2) 3 x 3-1/4 in. Discs	126	0.40	8.3	1.01	
	Int. Harvester	161	1100 D Travelall; V-345	x					Spiral substrate	0	0.46	5.1	4.51	
Matthey Bishop (Noble/Mono)	Johnson-Matthey		1972 Avenger; 1500 CC Cricket Engine	x	x				AEC 3A	0	0.11	1.65	0.85	Lead-Sterile fuel
	Brit. Leyland		MGB, 110 CID	x						0	0.14	1.02	2.41	
	Volvo	467/ OB 44448	1972 Model 144; Engine B20F	x					AEC 3A	100 1300	0.19 0.72	1.56 4.29	3.32 3.65	Converters empty at next test
	Daimler-Benz	2180	W-108								0.11	2.34	1.14	
	Saab	5/311	2.0 liter	x						0 2520	0.21 0.32	2.32 4.67	1.95 1.75	
Monsanto (Base/Pellets)	Saab	9/385	1.85 liter	x		Elect. Inject.			404	0	0.22	1.44	2.37	
	GM	2828	Buick 455	x	x				ECA-141	0	0.14	3.8	.1	
		61329	Chevrolet 402	x	x	x			NBP-70194	126	0.47	4.0	1.1	
Oxy-Catalyst (Base/Pellets)	GM	933	Buick 455	x	x				G-1313	0	0.19	1.8	2.4	
		2541	Oldsmobile 350	x	x	x				9	0.17	2.7	2.2	
UOP (Noble/Pellets)	UOP		1971 Chevrolet 350	x					PZ-224-M1	0	0.17	0.90		
									PZ-224-8605	0	0.07	0.73		
	Toyota		Toyota 1.600 liter	x	x				PZ-214	0	0.21	2.69		
	Saab		Saab 99E; 1.85 liter	x					PZ-216	403	0.19	3.15	3.77	UOP Mini-Verter (4-3/4 x 1.7 in.)
	Mitsubishi								PZ-226	0	0.05	1.04		Mitsubishi converter
	Volvo	602/ OB 44085			x					0	0.12	1.69	1.24	
UOP (Noble/Mono)	UOP		1971 Ford 351						2294-165	0	0.69	2.10		
			1971 Chevrolet 350						PZM-7711	0	0.38	1.65		
	Toyo Kogyo		Mazda 1.600 liter	x					PZM-17122		0.53	5.00		Estimated 1975 CVS-CH procedure

Table 5-1. (Continued)

Catalyst Mfr./Type	Testing Co.	Test/Car No.	Car and/or CID	System Description						Test Mileage	1975 CVS-CH Emissions, gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst		HC	CO	NO_x	
UOP (Base/Pellets)	UOP		1971 Chevrolet 351	x					PZ-1-214-3	0	0.14	1.21	3.53	GM converter
			1971 Chevrolet 350	x					PZ-1-214L-1	0	0.04	1.00	2.41	GM converter
	GM	932	Buick 455	x	x				PZ-4-214-R-14	0	0.19	1.8	2.4	
		61420	Oldsmobile 455	x	x	x			PZ-2-168-R-5	100	0.20	2.6	1.9	
Kali-Chemie (Base/Pellets)	Saab	7/301	1.85 liter	x		Elect. Inject.				0	0.22	2.85	1.02	
	Daimler-Benz	2324									0.10	1.70	0.28	
Degussa (Base/Pellets)	Saab	12/301	1.85 liter	x		Elect. Inject.				0 2580	0.19 0.74	2.11 15.66	1.66 2.52	
	Daimler-Benz	2377									0.14	2.3	1.0	
	GM	2826	Buick 455						OM 56 ET	10	0.38	3.5	3.3	
ICI (Noble/Pellets)	British Leyland	–	Austin Marina, 110 CID	x						0	0.19	1.38	2.08	
(Noble/Mono)	British Leyland	–	Austin Marina, 110 CID	x						0	0.18	12.29	2.33	
AC-Delco (Base/Pellets)	AM Motors	D11-3	258-6	x	x					0	0.23	1.47	2.12	
	Volvo	732/ OB 50430	1972 Model 144							120	0.24	2.43	3.14	
	Int. Harvester	393	1110 Travelall; V-392	x	x	x				0	0.35	4.56	3.11	

[a] 1972 CVS Test Procedure

fresh. However, when the catalysts are operated to extended mileages, the HC and CO emissions tend to rise to levels exceeding the 1975 standards. Table 5-2 summarizes typical best high-mileage or durability emission test data for the same catalysts shown in Table 5-1 at low-mileage conditions. The emission levels shown in these tables should be read with caution to prevent misinterpretation of the data. Emission test procedures included the seven-mode, 1972 CVS-C and 1975 CVS-CH procedures, which give different results and are difficult to correlate for different catalyst systems. Also, several data points which appeared on the table were based on "hot" test cycles which give considerably lower values than the corresponding "cold start" test. The method of accumulating durability mileage also varied, making any simple comparison difficult. Finally, many of the tests were run on catalyst test-bed vehicles, while others were run on laboratory prototype 1975 systems.

While a number of these catalysts met 1975 HC and CO standards at greater than 20,000 miles, the variation of vehicle test procedures (AMA durability runs, dynamometer runs, etc.) and the variation in test fuels and oils precludes a systematic assessment of the true capability of a given catalyst under projected EPA certification conditions. These conditions encompass the 50,000-mile EPA certification test specifications and the use of fuel with projected additive contaminant levels of 0.05 gm/gal lead (max.), 0.01 gm/gal phosphorus (max.), and conventional lube oils. Such an assessment can be made only with vehicles incorporating the full complement of 1975 emission control system components, tested in accordance with EPA certification procedures.

Catalyst durability is composed of two separate but interrelated aspects: emission durability and physical durability. Emission durability, or the ability to continue oxidizing HC and CO to the required levels throughout

Table 5-2. Summary of "Representative-Best" High Mileage Catalyst Data

Catalyst Mfr./ Type	Testing Co.	Test/ Car No.	Car and/or CID	System Description						Test Mileage	1975 CVS-CH Emissions, gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst		HC	CO	NO_x	
APCC (Houdry) (Base/Pellets)	GM	61318	Chevrolet 350	x	x	x			1259 JX3-1X1	21,178	0.87	4.[illegible]	1.6	Test continuing
		2233	Oldsmobile 455		x	x			1259 JX3-1X1	30,037	0.73	10.6	2.3	Test discontinued
AM Cyanamid (Base/Pellets)	No data													
Chemico (Base/Pellets)	No data													
Engelhard (Noble/Mono)	Engelhard		351-V8	x					PTX-433	35,821	0.35	3.0		Lead-free fuel and ashless lube oil
			Torino-351						(2) PTX-433-S	46,300	23 ppm[d]	40 ppm[d]		Commercial lead-free fuel and standard lube oil
			351-V8	x	x				Std. PTX-5	25,260	0.39	3.3	<3.0	Lead-sterile fuel and ashless lube oil
			351-V8	x	x				Imp. PTX-5	12,030	0.24	2.6	<2.2	Lead-sterile fuel and ashless lube oil
	Chrysler	20/333	360	x	x				0.2% Pt; twin	35,943	0.36[a]	4.7[a]	0.78[a]	Replaced monolith wrapping; temperature kept below 1500°F
		12/385	360	x	x				0.35% Pt	20,000	0.26[a]	2.84[a]	1.56[a]	Catalyst failed
		13/698	400	x					0.2% Pt; two 4 in.	43,000	0.16[a]	1.88[a]	3.91[a]	Converter damaged
	Volvo	1091/ OB 4408	1972 Model 144; Engine B20F	x	x				PTX-416	25,344	0.24	2.45	1.82	Catalyst failed at 29,900 mi (used 0.015 gm/gal lead)
	Am. Motors	D00-24	232-6	x					PTX-423-S (0.2% Pt)	50,000	0.32[b]	4.8[b]	2.1[b]	1970 type slow choke
	GM	61319	Chevrolet 350	x	x	x			PTX-4	21,527	0.55	5.5	1.6	
		17934	1971 Buick, 455	x					(2) PTX-423-S	70,000	0.85	8.7	3.5	70,000 mi high speed tire test run at Arizona track
	Brit. Leyland		Austin Marina, 110 CID						PTX (stacked)	17,000	0.63	4.65	1.32	
	Ford	1A58-D	1971 351 W-2V	x	x	x		Type H	PTX-5.35 (RH)	25,000	0.75[a]	7.97[a]	1.64[a]	Cold Emissions } Ford 1975 Durability Test Program
									PTX-5.10 (LH)		0.58[a]	7.81[a]	1.28[a]	Hot Emissions

Table 5-2. (Continued)

Catalyst Mfr./ Type	Testing Co.	Test/ Car No.	Car and/or CID	System Description						Test Mileage	1975 CVS-CH Emission, gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst		HC	CO	NO_x	
W.R. Grace (Base/Pellets)	GM	1450	Opel 1.9 liter	x	x	x			Davex 117	23,000	1.2	22.9	2.5	
(Noble/Mono)	Int Harvester	161	1100 D Travelall; V-345	x					Spiral substrate	16,000	0.46	6.85	3.99	
Matthey-Bishop (Noble/Mono)	Johnson-Matthey		1972 Avenger 1500 CC Cricket engine	x	x				AEC 3A	24,000	0.33	1.33	2.01	Lead-Sterile fuel
Monsanto (Base/Pellets)	Saab	9/385	1.85 Liter	x		Elect. Inject.			404	9,750	0.50	2.97	2.87	
	GM	61329	Chevrolet 402	x	x	x			NBP-70194	5,550	0.55	8.8	1.1	
		472	Buick 455	x					ECA-125	27,600	0.37^c	2.42^c	3.44^c	
										45,500	0.53^c	3.52^c	4.0^c	
Oxy-Catalyst (Base/Pellets)	GM	61317	Chevrolet 350	x	x	x			G-623-71	32,014	1.20	13.6	1.4	
		2850	Oldsmobile 455		x	x				18,000	0.58	7.4	2.7	
		2541	Oldsmobile 350	x	x	x				10,245	0.91	9.5	2.3	
UOP (Noble/Pellets)	UOP		1971 Ford 351						PZ-195 (in 2 mini-verters; 4-3/4 x 1.7"; 30 in.^{3}/bank)	21,933	0.47	2.65		Est. 1975 CVS-CH 20-25% catalyst lost Hot only
										25,086	0.74	2.46		
	Mitsubishi								PZ-216	7,000	0.25	4.33		
										8,000				Screen failure
(Noble/Mono)	UOP		1971 Ford 351						2294-165	12,500	1.07	1.59		Hot only
UOP (Base/Pellets)	UOP		1971 Chevrolet 351	x					PZ-1-214-3	7,180	0.13	5.25	2.52	After 1550 °F recycling of bed temperature
										7,722	0.06	1.15	2.48	
										15,875	0.30	2.90	3.00	More recycling
	GM	933	Buick 455	x	x				PZ-4-214-R-14	46,301	0.78	11.7	2.1	
		BAK	Buick 455	x					PZ-4-214-R-14	12,980	0.36	6.6	1.6	

Table 5-2. (Continued)

Catalyst Mfr. / Type	Testing Co.	Test/ Car No.	Car and/or CID	System Description						Test Mileage	1975 CVS-CH Emissions, gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst		HC	CO	NO_x	
Kali Chemie (Base/Pellets)	Saab	7/301	1.85 Liter	x		Elect. Inject.				5,900	0.25	3.63	1.96	
ICI (Noble/Pellets)	Brit. Leyland		Austin Marina, 110 CID							9,200	0.20	2.61	2.21	
(Noble/Mona)	Brit. Leyland		Austin Marina, 110 CID							4,500	0.25	1.14	2.44	
AC-Delco (Base/Pellets)	Am. Motors	D17-11	258-6	x	x					32,000	0.51[b]	3.4[b]	1.9[b]	
	Int. Harvester	393	1110 Travelall; V-392	x	x					20,000	0.51	8.76	3.00	

[a] 1972 CVS Test Procedure [b] Least-squares straight line value [c] 7-mode data [d] 7-mode hot start data

50,000 miles, is most strongly impacted by decremental changes in catalytic activity or efficiency caused by:

a. Contamination from fuel and oil additives or compounds (e.g., lead, phosphorus, sulfur, etc.) resulting in "poisoning" of the catalytic material

b. Reduced alumina porosity due to phase change at excessive temperature

c. Alumina thermal shrinkage due to excessive temperature

Physical durability, or the ability to maintain the substrate intact throughout 50,000 miles, is most strongly impacted by

a. Thermal expansion differences between monolithic ceramic substrates and their supporting container

b. Local melting of monolithic ceramic substrates due to overtemperature

c. Failure of pellet retaining screens due to overtemperature

d. Cracking of monolithic ceramic substrates and breakup of pellet substrates due to vibratory loads

In addition to loss of emission control, physical failure of either monolithic or pellet catalytic converters due to either overtemperature conditions or rupture of the canister can cause vehicle fires, posing a serious vehicle safety hazard.

A number of solutions to the above oxidation catalyst problem areas are currently under active consideration or development by the Federal Government, the catalyst suppliers, and the auto makers, as follows.

a. Fuel additive regulation. The Administrator of EPA is currently proposing to regulate the level of lead (0.05 gm/gal max.) and phosphorus (0.01 gm/gal max.) in gasoline to reduce the effects of these catalyst "poisons" to hopefully tolerable levels.

b. Overtemperature protection. Various methods of thermal control are being developed by the auto makers to protect the catalyst from overtemperature conditions. In one system, control is effected by precise regulation of engine exhaust conditions at the inlet to the catalyst bed. In another proposed system, control is effected by bypassing the catalyst bed when the exhaust gas HC and/or CO level or temperature is excessive.

c. Improved catalyst properties. The catalyst suppliers are improving both the physical strength and activity of their catalysts.

d. Improved catalyst containers. Both catalyst suppliers and auto makers are developing catalyst containers with improved design features to overcome thermal differential expansion and vibration effects.

The proposed innovations and development activities described above reflect a technology that is rapidly changing through intensive product design modifications, as well as through comprehensive test and evaluation programs in both the catalyst industry and the automotive industry. Because of these rapid changes, the activity and durability data frequently reported as latest results are based on catalyst materials and substrates which may in fact be "old technology" previously discarded by others. Due to the time delay inherent in the relationship between the substrate-catalyst-converter suppliers and the auto makers themselves, it is not surprising that some problems reported as severe by one company are treated as solved by others. Some recent data presented by the catalyst makers with their latest technology have indicated encouraging results at relatively high mileage; however, it remains to be seen whether these catalysts can maintain good performance when tested in a prototype emission package under realistic driving conditions by the auto manufacturers.

5.2 CATALYST TYPES

A catalytic converter is a device containing a catalyst material which promotes chemical reactions which would otherwise occur very slowly. Those catalysts which promote the oxidation of HC and CO into carbon dioxide (CO_2) and water (H_2O) are referred to as "oxidation catalysts," "HC/CO catalysts," or "HC/CO oxidation catalysts." A great effort has gone into developing this type of catalyst for automotive application and literally hundreds of combinations have been tested, including base metals, precious metals, and combinations of both. The HC/CO oxidation catalysts, as the name implies, require excess oxygen (air) to convert the HC and CO to H_2O and CO_2. This can be accomplished by operating the engine at lean air-fuel mixtures or by adding secondary air to the engine exhaust upstream of the catalyst. To date the latter approach has been used almost exclusively.

Both base metal and noble metal catalysts are under intensive evaluation and development by the automobile industry. Specific configurations of catalysts and catalytic converters vary widely. One approach is to use a monolithic coated substrate contained in a cylindrical shell. Another approach is to use a pelletized form of catalyst held in place by interior louvered members, within an outer container. In general, the specific structural and chemical formulations are considered trade secrets by the catalyst suppliers. Necessary attributes for catalytic converters for automotive use include sufficient chemical activity, long life, resistance to mechanical shock, and high-temperature capability.

5.2.1 Typical Catalysts

Hundreds of catalyst types have been examined for possible use in controlling automotive emission of HC and CO. Usually, these catalysts were first tested in laboratory-scale experiments, with the more promising ones then tested in engine dynamometer tests and, finally, in vehicle road tests.

5.2.1.1 Base Metal Catalyst

Base metal catalysts employ metals or oxides of metals from the transitional group of the Periodic Table of Elements which includes vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), and zinc (Zn). Several metals and their oxides are usually combined to form a catalyst (e.g., Cu-Cr, Cu-Mn). Supports such as alumina (Al_2O_3)

and/or silica (SiO_2) are used to provide structural strength. Notice that a few base metal catalysts also incorporate trace amounts of noble metals such as platinum (Pt) or palladium (Pd).

5.2.1.2 Noble or Precious Metal Catalysts

The noble or precious metal catalysts that have been tested are primarily Pt and Pd. They are deposited on Al_2O_3, SiO_2, or cordierite supports (see Section 5.4) and are characterized by relatively low concentrations of active metal (approximately from 0.1 to 0.6 percent by weight). In general, an alumina or promoted-alumina "wash coat" is applied to the substrate prior to the deposition of the noble metal on monolithic cordierite substrates.

5.2.2 Automotive Catalyst/Substrate Combinations

Most catalyst suppliers and/or automotive users refer to a catalyst type by substrate (or support) type, in addition to the type of catalytic material involved. The substrate is the material on which the active catalyst component (and wash coat, when used) is coated, and can be either a pellet, or a monolithic structure.

The pellet (or bead, or particulate) type of substrate consists of small individual alumina (Al_2O_3) pellets which can be of a variety of shapes ranging from spheres to elongated cylindrical rods. They are generally small in cross-section or diameter (approximately from 1/8 to 3/16 inch), thus requiring many such pellets for a catalytic converter.

The monolithic type of substrate refers to a single unit structure or package, generally of honeycomb configuration to provide the necessary surface area for chemical reactions. While referred to as monolithic, the structure may in fact be composed of layers of corrugated material stacked together to comprise the entire monolithic unit. Such structures are usually composed of cordierite materials.

The following catalyst/substrate combinations are those reported to be of principal interest for automotive HC/CO oxidation catalytic converters: base metal/pellets, noble metal/pellets, and noble metal/monoliths.

A fourth possible combination, base metal/monolith, apparently is not under active development or consideration. General Motors has stated that a suitable base metal/monolith catalyst has not been made available by catalyst suppliers.

5.3 SPECIFIC CATALYST FEATURES (BY COMPANY)

The following sections briefly describe the known characteristics or design features of specific catalysts supplied to the automotive industry by the various catalyst suppliers for evaluation. Such definitions are limited to the extent disclosed in the recent EPA 1975 Suspension Hearings or as disclosed in communications between the catalyst manufacturers and the Division of Emission Control Technology, EPA, Ann Arbor, in April 1972.

Table 5-3 is a brief summarization of the catalyst suppliers and their products, as discussed below.

5.3.1 Air Products and Chemicals, Inc. (Houdry Division)

The Houdry Division of Air Products and Chemicals, Inc. has been principally concerned with developing base metal/pellet catalysts (Ref. 5-1). It has supplied four different catalysts of this type (designated A, B, C, D) to the AC-Delco Division of General Motors and two other catalysts (E and F) to Chrysler Corporation.

While its catalysts are designated base metal, some are promoted with small concentrations of precious metal.

It is not clear whether Houdry fabricates the pellet or not. It apparently has been involved in a program of improving the pellet durability properties, however this could relate to thermal and other treatments instead of direct pellet fabrication from raw materials.

Table 5-3. Potential Catalyst Suppliers

Company	Products				
	Base Metal	Noble Metal			
	Pellets	Pellets	Monoliths	Supplied To	Remarks
UOP	X	X		U.S. auto companies and many foreign manufacturers (including Volvo), GM (and others)	Noble metal pellet (spherical) is UOP's first choice
Oxy-Catalyst	X	-	-		
Matthey-Bishop	-	-	X	4 U.S. and 20 foreign auto manufacturers	
W.R. Grace	Davex 142	-	Davex 502	GM, Ford, Chrysler, and foreign manufacturers	
Engelhard	-	-	(PTX Series)	Most auto companies	Under supply contract to Ford
Monsanto	X			Saab, Chrysler, GM	
American Cyanamid	X			GM	Claim recent thermal and attrition improvements
Chemico	X			None (Tests at GM)	Consultant role only
APCC (Houdry)	X			AC-Delco (A, B, C, D) Chrysler (E, F)	Some promoted with small amounts of precious metals
Union Carbide	Catalytic metal choice unknown. Support would be flexible fibers in various forms (tow, yarn, felt, monoliths)			-	Not targeted for 1975 use (developmental only)
Kali-Chemie	X			Saab, Daimler-Benz	
Degussa	X			Saab, Daimler-Benz, GM	
ICI				Brit. Leyland	Noble metal pellet or monolith.

5.3.2 American Cyanamid

Automotive catalyst development efforts of American Cyanamid have been concentrated on base metal/pellet catalysts (Ref. 5-2). It is known to have supplied such catalysts to General Motors, and may have supplied others. Cyanamid claims to have made recent improvements in thermal stability and attrition characteristics of their catalysts.

Cyanamid has no real position in the monolithic catalyst area.

5.3.3 Chemico

Chemico is not a commercial producer of catalysts (Ref. 5-3). However, it has been developing an emission control system which incorporates a base metal/pellet catalyst. Its position is that it is trying to develop a technology and would plan to market that technology to other companies as a consultant.

Chemico has had discussions with the four major domestic automobile manufacturers and with a number of suppliers. To date, Chemico has signed testing agreements with GM, Chrysler, and Ford.

5.3.4 Engelhard Industries

Engelhard's principal automotive oxidation catalyst product is the exhaust gas purifier tradenamed "PTX" (Ref. 5-4). In brief, PTX is a noble metal (platinum)/monolith catalyst. As supplied in the past it is cylindrical, although there is no reason it could not be (and may be) provided in other shapes (e.g., oval, square, etc.). The monolithic substrate utilized to date has been the corrugated ceramic produced by American Lava (tradenamed "ThermaComb") in both stacked (laminated) and spiral (rolled-up) configurations. Again, the Corning monolithic substrate (designated W-1) could be used as well.

Engelhard has supplied PTX automotive catalysts to a number of domestic and foreign auto manufacturers for evaluation. In general, most of these have been of the standard PTX design (e.g., PTX-433, PTX-433S, PTX-5, PTX-423S, etc.). Engelhard also claims an improved PTX catalyst which has better high temperature stability and light-off temperature characteristics.

Engelhard is currently under contract to Ford for PTX catalyst supply (with the American Lava "ThermaComb" substrate).

5.3.5 W.R. Grace and Co.

W.R. Grace and Co. has developed two oxidation catalyst types and supplied them to automobile manufacturers for evaluation (Ref. 5-5). One is a base metal/pellet catalyst (Davex 142) that employs an alumina support material not commercially available (fabricated by Grace). The other is a noble metal/monolith catalyst (Davex 502) which employs a unitary ceramic support. The monolith supports used by Grace to date have been those commercially available from American Lava and Corning, and developmental supports provided by an outside supplier and an internal Grace research program.

Grace has supplied catalyst samples to GM, Ford, Chrysler and a number of foreign manufacturers.

Grace indicates the costs for their products shown in the following table:

Code Name	Type Catalyst	Cost to Automotive Companies
Davex 142	Base Metal Pellet	\$1 - \$1.25/lb @ ~ 7-1/2 lb \$7.50 - \$9.50 per unit$^{(1)}$
Davex 502	Noble Metal Monolithic$^{(2)}$	\$11 - \$13 per unit$^{(3)}$

(1) one unit per car

(2) 0.026 oz Pt and 0.026 oz other noble metal per converter.

(3) two units per V-8 engine, one for 6-cyl engine.

5.3.6 Matthey Bishop, Inc.

Matthey Bishop is a wholly owned subsidiary of Johnson-Matthey & Co., Ltd. Its principal automotive catalyst product is a noble metal (platinum)/monolith developed by the Matthey Bishop Research Laboratories, Malvern and the Corporate Research Center, Wembley, England (Ref. 5-6). Its most recent catalyst product is designated the "AEC 3A" oxidation catalyst. It is collaborating with four US auto manufacturers and twenty British, European, and Japanese manufacturers.

Matthey Bishop feels its noble metal/monolith unit does not use excessive platinum (0.04 oz/unit; two units required for a V-8 engine) and would have reasonable cost ($10-$15/unit without container) to automobile manufacturers.

5.3.7 Monsanto

It is known that Monsanto has provided base metal/pellet catalysts to some auto makers. However, no information from Monsanto was available for consideration.

5.3.8 Oxy-Catalyst, Inc.

Oxy-Catalyst has manufactured and installed many thousands of catalytic exhaust purifiers on all types of industrial vehicles powered by IC engines (forklift trucks, etc.). Its principal products were OC-100 (the tradename for their pellet purifier) and Oxy-Cat (their platinum/monolith unit).

For automotive application it is most seriously considering base metal/pellet catalysts and has been supplying GM through the AC Spark Plug Division. It has supplied 76 of the 368 base metal pelleted formulations tested by GM (Ref. 5-7).

Oxy-Catalyst has given GM a price quotation of about $1 per lb (6 lb/converter). The pellet alumina substrate is obtained from outside vendors from among Reynolds, Kaiser, Alcoa, and Pechiney.

5.3.9 Union Carbide Corporation

Union Carbide is in the developmental stage of automotive catalysts employing a proprietary ceramic fiber as a catalyst support (Ref. 5-8). These flexible fibers can be prepared in a multitude of forms, such as yarn, felt, tow, and various monolithic structures. Union Carbide has not identified any choice or restriction as to base or noble metal catalytic material.

Union Carbide does not expect to have a viable catalyst entry until 1976; therefore, it is not a contender for 1975 systems.

5.3.10 Universal Oil Products Company

The Purzaust group of UOP has developed three different oxidation catalyst candidates for use in 1975 (Ref. 5-9). They are base metal/pellets, noble metal/pellets, and noble metal/monolith.

Currently UOP has working programs with the U.S. and many foreign automobile manufacturers on the development of catalysts and catalytic converters.

One new UOP development is the Mini-Verter. This is a small (30 in^3), simple, and reportedly inexpensive converter charged with a small quantity of highly active catalyst material designed to operate at elevated temperature levels. Universal Oil Products Co. believes the noble metal spherical pellet catalyst offers the most promise in automotive application.

5.3.11 Miscellaneous

A number of other potential catalyst suppliers (e.g., Kali-Chemie, Degussa, ICI, etc.) have products which are not described herein due to a lack of detailed information.

5.4 SUBSTRATE AND CONVERTER DESIGN FEATURES

5.4.1 Substrate Features (By Company)

The following sections briefly describe the known characteristics or features of specific catalyst substrates supplied to the catalyst suppliers by the substrate producers. Such definitions are limited to the extent disclosed in the recent EPA 1975 Suspension Hearings or as disclosed in communications between the substrate manufacturers and the Division of Emission Control Technology, EPA, Ann Arbor, in April 1972.

Table 5-4 is a brief summarization of substrate suppliers and their products, as discussed below.

5.4.1.1 Alcoa

Alcoa has supplied alumina pellet substrates to catalyst manufacturers for catalyst preparation (Ref. 5-10). Alcoa both mines and processes alumina ore. Alcoa already manufacturers pellets for nonautomotive catalyst preparations and has supplied these and modified pellets to various catalyst manufacturers. Alcoa has contacted 13 firms with whom it has been working. To date, Alcoa has not produced a satisfactory catalyst substrate and has been unsuccessful in obtaining Low density, High thermal stability, Pellet strength, and Effective catalyst life.

Alcoa does not feel that it can produce a successful substrate pellet although it has been trying to do so for 18 months. Alcoa feels the catalyst companies will make their own pellet. However, Alcoa does hope to supply alumina powder to catalyst manufacturers to make their own pellets. Alcoa could also play a role in supplying whatever alumina was needed for ceramic monolith substrates.

5.4.1.2 American Lava Corporation

American Lava has produced honeycomb and split-cell type corrugated ceramic catalyst supports (tradenamed "ThermaComb") for ten years (Ref. 5-11). ThermaComb substrates, until the very recent availability of the Corning W-1 substrate, have been the principal monolithic substrates used in noble metal/monolith catalysts evaluated for automotive application (e.g., Engelhard, Matthey Bishop catalysts).

The two ceramic compositions currently available in corrugated structures are alpha alumina, Al Si Mag® 614 and 776, and cordierite, Al Si Mag® 795. The two alumina bodies differ only in the porosity level and physical properties that are affected by porosity as shown in Table 5-5 (Ref 5-11).

Table 5-4. Potential Catalyst Substrate Suppliers

	Product			
Company	Raw Materials	Pellets	Monoliths	Remarks
UOP		X	X	For own catalyst use only
Union Carbide	Ceramic Tow, yarn, felt fibers (flexible)	-	X	Not targeted for 1975 use (developmental only)
Reynolds		X (Alumina)	-	Can supply in quantity at \$0.41/lb
Kaiser	Alumina powders	X (Alumina)	-	Would supply both raw materials and pellets
W.R. Grace		X (Alumina)	- (Development item)	For own catalyst use only
Corning			X (Cordierite)	Recent entry in monolith substrate field
American Lava			X (Cordierite)	Principal substrate used to date for noble metal/monolith catalysts
Alcoa	Alumina powders	-	-	Will not manufacture substrate - suppliers of raw materials only

Table 5-5. Alumina Body Physical Properties

Materials:		Alsimag 614	Alsimag 776	Alsimag 795
		Dense 96% Alumina	Porous 96% Alumina	Cordierite
Property	Unit	Highest mechanical strength. Good corrosion resistance.	For catalyst carriers and special applications.	Good thermal shock resistance. Excellent as catalyst carrier.
Water Absorption	%	0	17	25-30
Safe Operating Temperature	°C °F	1538 2800	1200 2192	1200 2192
Specific Gravity of Material Web		3.65	2.5	1.7
Specific Heat	Btu/lb. °F.	0.21	0.21	0.19
Coefficient of Thermal Expansion	in./in./°F. 70-1400°F.	4.4×10^{-6}	3.9×10^{-6}	2.1×10^{-6}
Thermal Shock Resistance		Fair	Good	Excellent
Compressive Strength (Parallel to Passages)	Psi (5c/in. SC) 0.016 Thick Web	15,500	8,500	2,750
Modulus of Rupture	Psi (4 in. Centers, 1 in. x 1 in. Beam, 5c/in. SC)	2,800	1,500	1,800
Thermal Conductivity	Solid Ceramic @ 570°F. Btu in./hr. ft.^{2} °F.	119.0	85.0	10

Cordierite is the mineralogical name for the ternary oxide $2\ MgO\cdot 2Al_2O_3\cdot 5\ SiO_2$ and this compound is the primary constituent in Al Si Mag®795.

The basic differences between the split cell and honeycomb structures are shown in Figure 5-1. Also pictured is the cross-flow split cell design, the crisscross split cell, and the crisscross honeycomb.

Two basic forming methods are used to make the corrugated products, stacking and rolling. They are illustrated in Figure 5-2. The rolled structures are available only in Al Si Mag®795, split cell configuration.

The stacked structures were those first used by the catalyst makers in developing noble metal/monolith units, then rolled structures were utilized. More recently, the catalyst makers (e.g., Engelhard, Matthey Bishop) have reverted to the use of the stacked structures.

American Lava will be one of the monolith suppliers for Ford (via Engelhard), and has been in contact with Matthey Bishop, W. R. Grace, and Universal Oil Products.

5.4.1.3 Corning Glass Works

Corning Glass Works has concentrated on the development of a monolithic multicellular ceramic substrate for use as a catalyst carrier (Ref. 5-12). It has invented a process which allows it to form the ceramic substrate in a wide variety of shapes. The product is truly monolithic, since it is made all at one time, and it is made by a process that is fast and precisely controllable. This product, called W-1, was introduced to catalyst and automobile manufacturers in December 1971. Catalyst companies have been able to apply catalysts to this substrate without difficulty. To date, tests have shown that catalytic activity and durability are equal to that of other acceptable supports.

Corning's cordierite ceramic monolithic substrate material is different from conventional monoliths. It may be easier to make and the cross-sectional shape of the monolith can be easily varied. Corning is quoting between 5¢

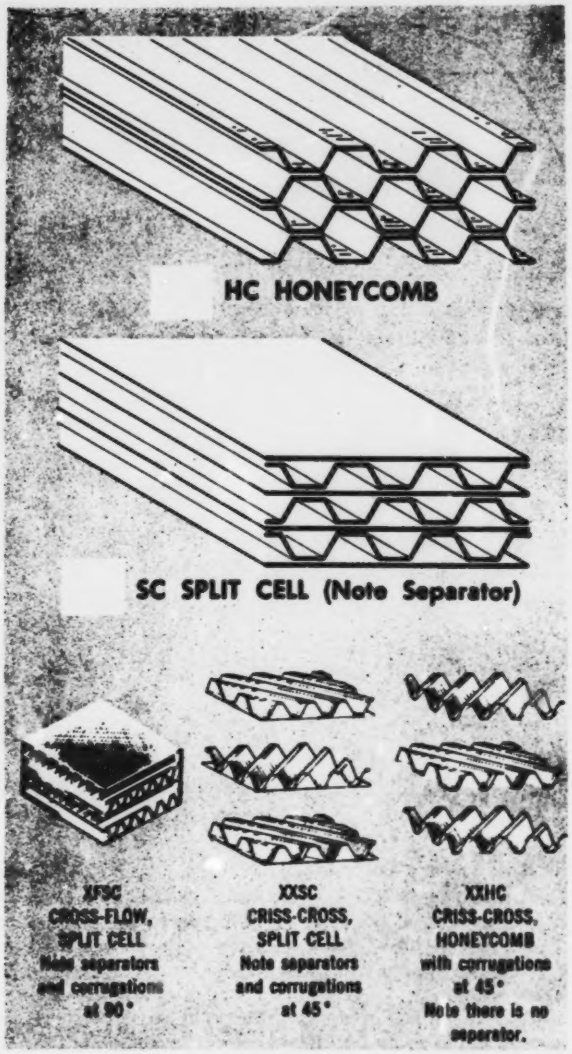

HC HONEYCOMB
SC SPLIT CELL (Note Separator)
XFSC
CROSS-FLOW,
SPLIT CELL
Note separators
and corrugations
at 90°
XXSC
CRISS-CROSS,
SPLIT CELL
Note separators
and corrugations
at 45°
XXHC
CRISS-CROSS,
HONEYCOMB
with corrugations
at 45°
Note there is no
separator.

Figure 5-1. Corrugated Structure Types

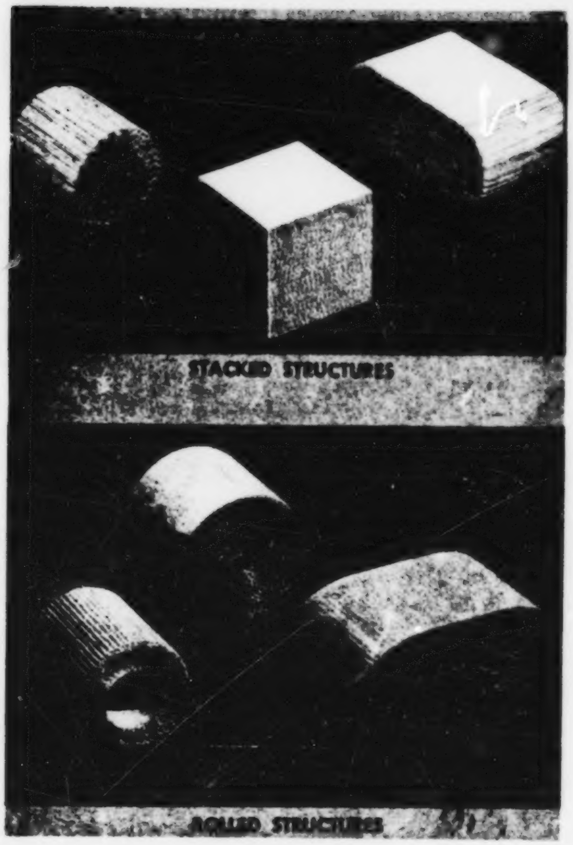

STACKED STRUCTURES
ROLLED STRUCTURES

Figure 5-2. Stacked and Rolled Corrugated Structures

and 5-1/2¢ per cubic inch for this material to Chrysler and Ford, and assumes that approximately 100 cu in. per vehicle will be sufficient for a total substrate cost of $5.00 to $5.50. The cost of the substrate is somewhat influenced by volume; less so, within limits, by its shape. Limited durability data are available from Corning. The automotive manufacturers also have this data. Corning feels their material has mechanical properties superior to that of their competition.

Corning claims that the material from which it makes the substrate will present "absolutely no supply problems." The Corning substrate is being considered for use by one or more of the following catalyst firms: Johnson Matthey, Engelhard, Grace, Monsanto, Houdry, and/or Universal Oil Products.

Information provided by Johnson-Matthey (Ref. 5-13) on Corning W-1 substrate properties is given in the following listing:

Designation	Corning W-1
Composition	Cordierite
Type	Glass Ceramic
Configuration	Rectangular Grid
Wall Thickness (in)	0.009
Open Area (percent)	74
Superficial Surface Area (ft^2/ft^3)	720
Bulk Density (lb/ft^3)	28
Expansion Coefficient (per $^oF \times 10^{-7}$)	12.2
Axial Crush Strength (psi)	7000
Porosity (percent)	31
Max. Service Temperature (^oC)	1200
Wash Coat	Yes
Metal Area (m^2/gm Total Metal + Wash Cost + Support)	0.17
Surface Area (m^2/gm Total Metal + Wash Coat + Support)	18-20

5.4.1.4 W.R. Grace

As mentioned in Section 5.3-5, W.R. Grace manufactures its own alumina pellet for their Davex 142 base metal/pellet catalyst. Grace also has an in-house developmental monolithic support which may be used for its Davex 502 noble metal/monolith catalyst (Ref. 5-5).

5.4.1.5 Kaiser Chemicals

Kaiser Chemicals is a producer of basic alumina materials and a supplier of formed (or beaded) pellet catalyst substrates (Ref. 5-14). Three Kaiser products have now undergone various stages of performance evaluation; namely, catalyst substrate alumina powder, type "sa", catalyst substrate alumina spheres, type "sas", and catalyst substrate alumina spheres, type "sp". Both the "sa" and the "sas" materials are now being produced on a commercial scale. The type "sp" material is still in a developmental stage in that it has not been produced in plant scale equipment. This new product, if satisfactory, offers cost savings compared to types "sa" and "sas" substrates.

5.4.1.6 Reynolds Metals Company

Reynolds is a major producer and marketer of chemicals generally associated with the production of aluminum metal. Although aluminum melts at 1200°F, the oxide of aluminum (Al_2O_3, or alumina) is a very stable substrate material capable of withstanding 3500°F temperatures while remaining relatively chemically inert. It can be heat treated so that it has a large interior surface area, which is a necessary attribute for pellet substrates.

Reynolds Aluminum Research Division has developed supports which are of interest to several of the catalyst manufacturers (Ref. 5-15).

Reynolds to date has two major pellet candidates which have adequate durability and attrition resistance as determined by bench scale testing. Reynolds feels its pellets are performing satisfactorily in vehicle durability tests. However, Reynolds recognizes that subsequent treatment of its pellets by the catalyst manufacturers changes physical durability characteristics of the pellet. These changes make durability data supplied by the automobile or catalyst manufacturers more meaningful than data from Reynolds. Reynolds, therefore, cannot state whether the durability of its support is sufficient for an acceptable catalyst.

Reynolds does have the ability to supply these supports in necessary quantities and has quoted price estimates of $0.41/lb.

Reynolds has supplied samples to the firms with which they have active working agreements. These are W. R. Grace, Engelhard, Air Products and Chemicals, Monsanto, and Oxy-Catalyst.

5.4.1.7 Union Carbide

As mentioned in Section 5.3.9, Union Carbide is developing a proprietary ceramic fiber for catalyst support application. These flexible fibers can be prepared in a multitude of forms, such as tow, yarn, felt, and various monolithic structures. This material would be applicable to both base and noble metal catalysts. These supports are not expected to be sufficiently well developed for 1975 oxidation catalyst use, but may be a 1976 support contender.

5.4.1.8 Universal Oil Products

Universal Oil Products (UOP) has conducted research and development of both spherical pellet substrates and monolithic substrates (Ref. 5-9). If UOP produced such substrates, presumably it would be for its own finished catalyst product and not for supply to other catalyst makers.

5.4.1.9 Miscellaneous

Matthey Bishop has reported (Ref. 5-13) that it has examined some alternatives to the ThermaComb and W-1 monolith substrates, including the following:

a. A reaction bonded silicon nitride (Si_3N_4) honeycomb similar in configuration to ThermaComb. It does not require a wash coat (to promote at least short term activity) and has a higher light off temperature and lower conversion efficiency than ThermaComb or W-1. The material is also stated to be too expensive for other than experimental use.

b. A rigid fibrous form of alumina, Fibral 80, which does not require a wash coat. Although Fibral 80 is remarkable for an ultra-low light off temperature, it suffers from relatively low conversion. The conversion problem is attributed to an ineffective configuration which the manufacturer is currently modifying.

c. Monoliths recently have become available in development quantities from Champion Spark Plug, Hexcel Corporation, and Owens-Illinois. No data on these designs are yet available.

5.4.2 Converter Design Features (By Company)

5.4.2.1 AC Division, General Motors

In the recent EPA Suspension Hearing testimony, GM (Ref. 5-16) indicated that its AC Division had primary responsibility for catalysts and that the Oldsmobile Division was the lead division for converter development. However, other companies utilizing or testing such GM-supplied catalytic converters refer to them as AC or AC-Delco converters.

The AC converter is comprised of a pancake-shaped canister, shown in Figure 5-3, which houses pelletized catalysts. The exact mechanical interior features are not specified, but would necessarily include either a louvered interior pellet-holder or a screen-retainer arrangement for holding the pellets.

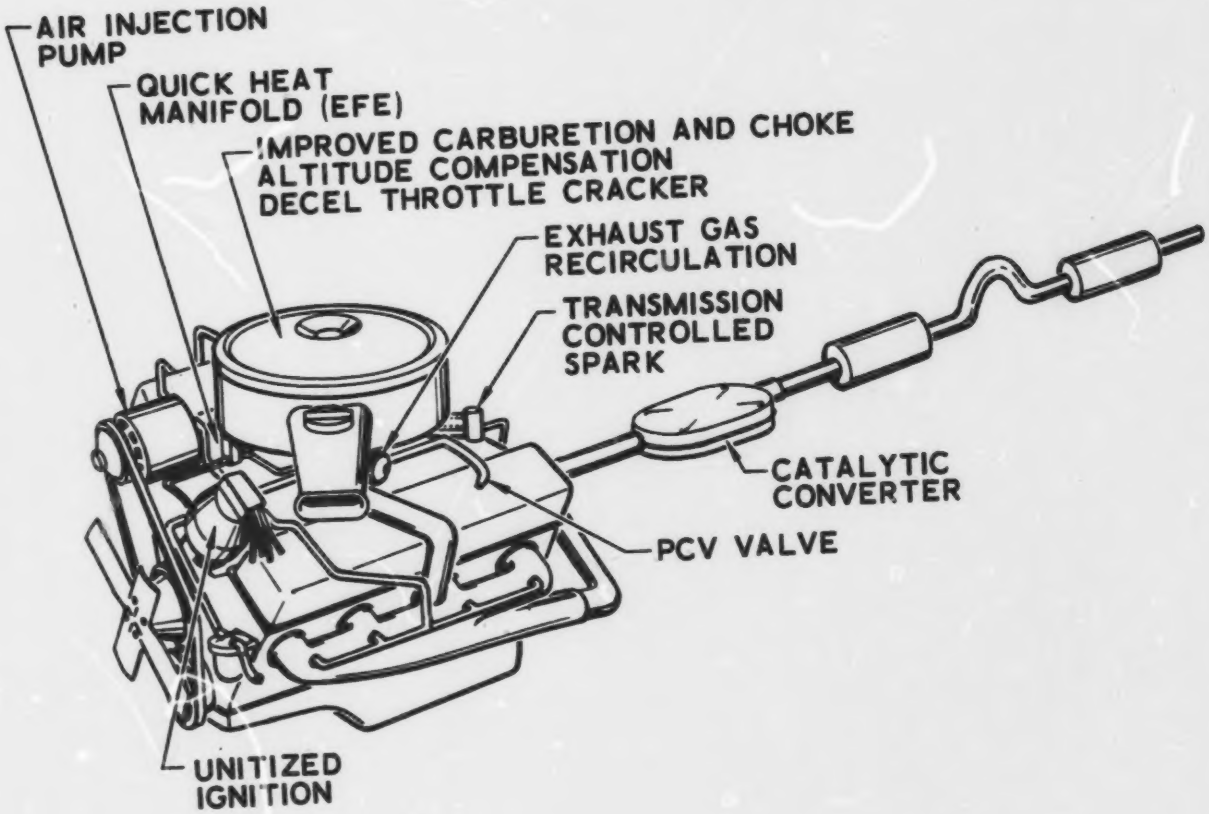

AIR INJECTION PUMP
QUICK HEAT MANIFOLD (EFE)
IMPROVED CARBURETION AND CHOKE
ALTITUDE COMPENSATION
DECEL THROTTLE CRACKER
EXHAUST GAS RECIRCULATION
TRANSMISSION CONTROLLED SPARK
CATALYTIC CONVERTER
PCV VALVE
UNITIZED IGNITION

Figure 5-3. AC Pancake Converter Installation

General Motors indicates the canister will be fabricated of a new nonnickel-containing steel, GM-6125-M, which was developed by the steel companies expressly for GM.

5.4.2.2 Chrysler

Chrysler (Ref. 5-17) has utilized a number of converter types in evaluating catalysts, including the GM (AC or AC-Delco) pebble-bed converter, a cylindrical monolith converter, a dual cylinder monolith converter, and an oval monolith converter.

The cylindrical monolith converter is shown in Figure 5-4; the dual cylinder monolith converter in Figure 5-5; the oval monolith converter in Figure 5-6. In general, all have metal (stainless steel) containers which house the monolithic catalyst element and any retaining or support elements; e.g., wire support mesh between monolith and container.

Chrysler has tested a number of pellet type catalysts with the "GM pebble-bed" converter, including W. R. Grace Davex 45 V, Monsanto ECA 302, W. R. Grace Davex 137, Houdry (Air Products & Chem.) 1057JXB-2X1, an American Oil Co. Catalyst, and a UOP Three-Way Catalyst.

Cylindrical monolith converter tests have utilized Engelhard PTX and W. R. Grace Davex 47 V catalysts.

Oval monoliths have apparently been limited to Engelhard PTX catalysts. At least one of these incorporated the new Corning W-1 substrate, in that it was referred to as "extruded" substrate.

5.4.2.3 Engelhard

In addition to providing the bare monolithic catalyst core element (i.e., PTX element), Engelhard also will provide a canister for containment of this element. Engelhard has a patented proprietary core containment device or arrangement to provide mechanical support for the ceramic core element

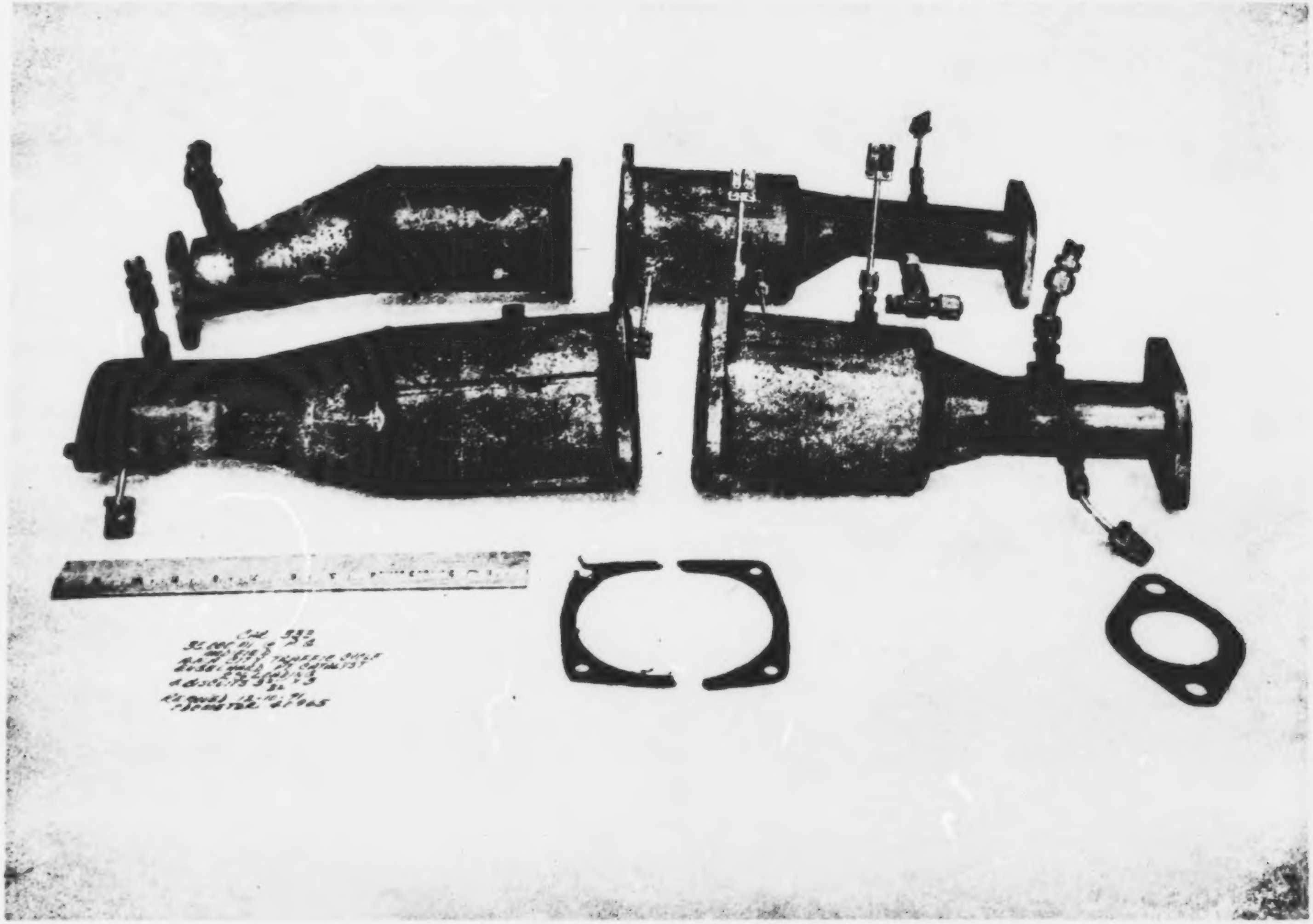
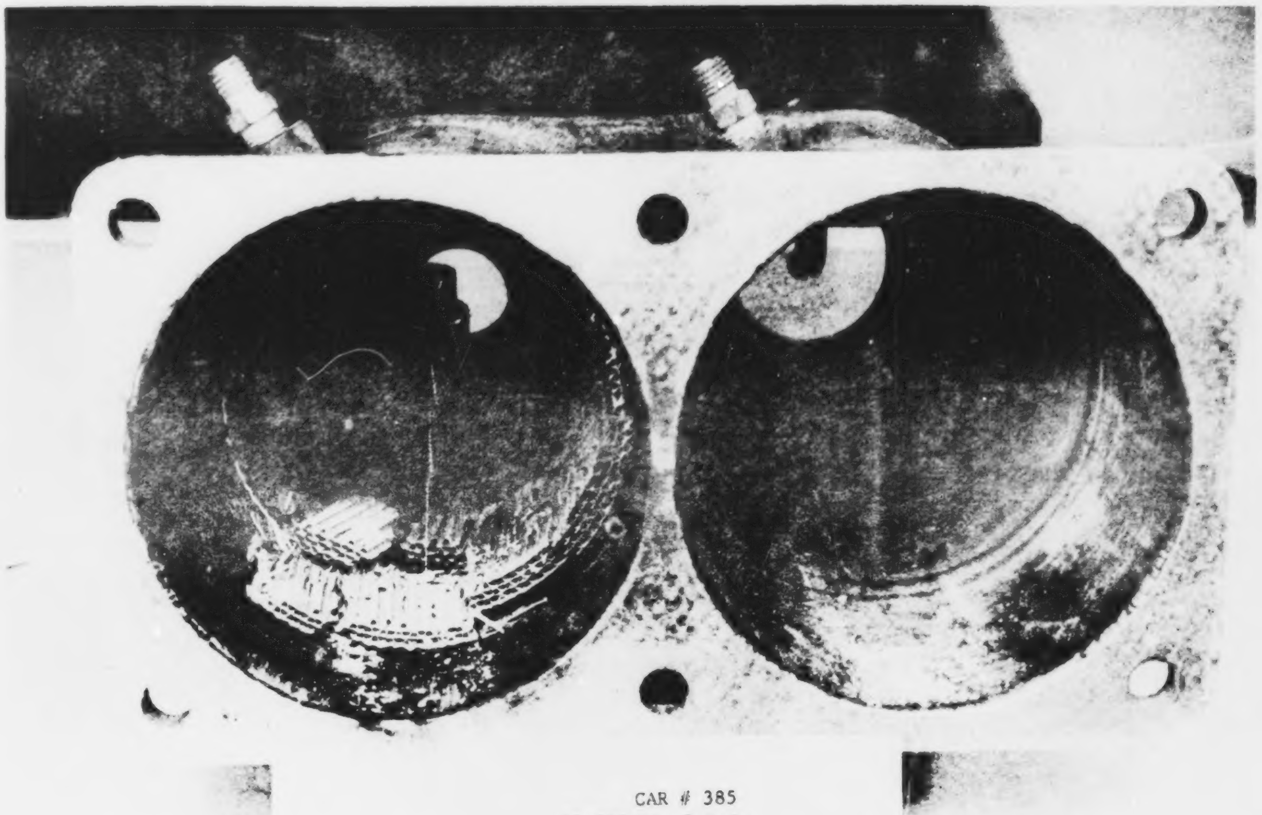


Figure 5-4. Chrysler Cylindrical Monolothic Converter



CAR # 385
23,000 MI. @ P.G.

A. M. A. ENDURANCE TEST

ENGELHARD PT. CATALYST
.35% LOADING

4 BISCUITS 4.00 O.D. X 3"

REMOVED 11/24/71

Figure 5-5. Chrysler Dual Cylinder Monolithic Converter

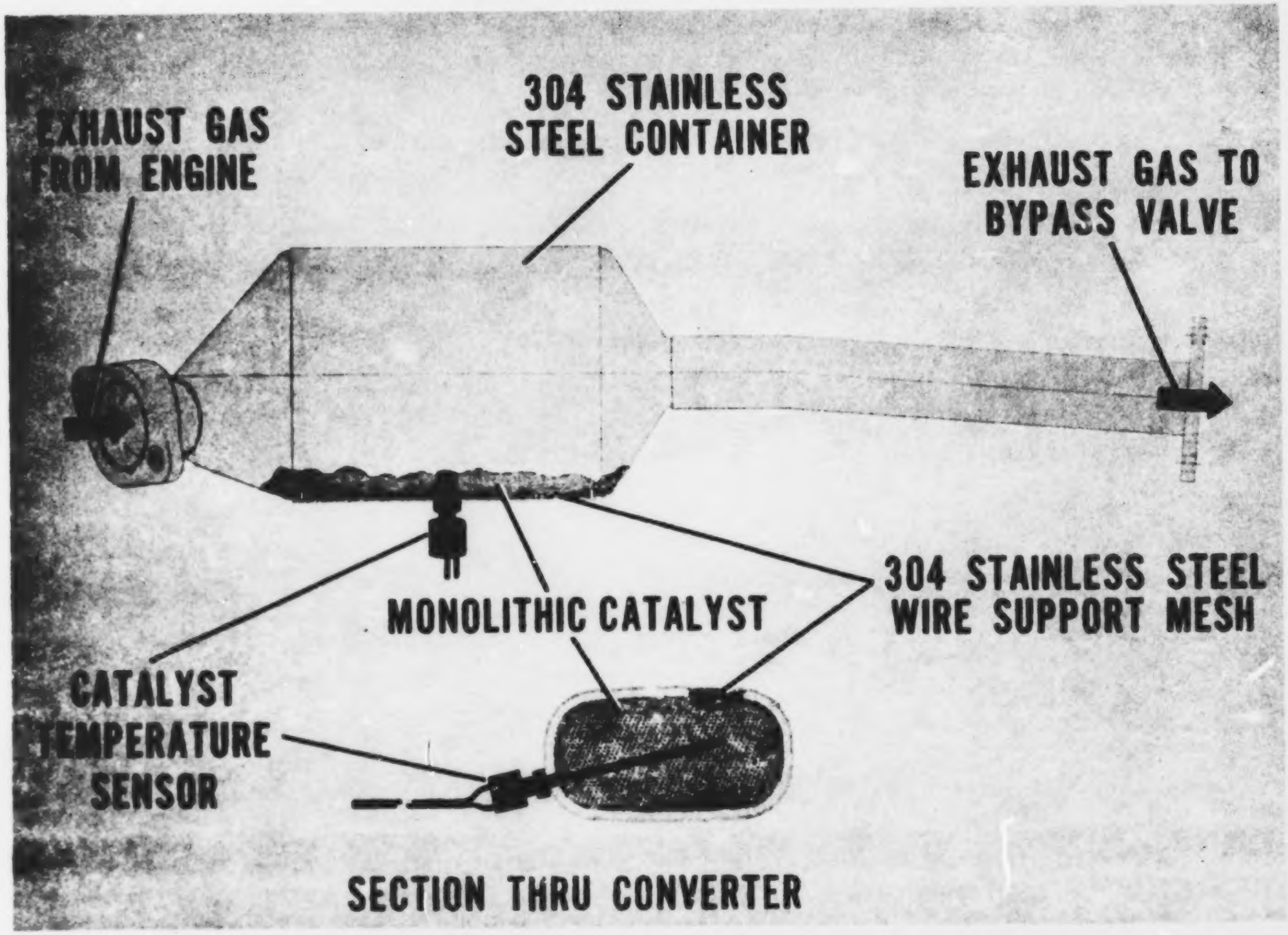

EXHAUST GAS FROM ENGINE
304 STAINLESS STEEL CONTAINER
EXHAUST GAS TO BYPASS VALVE
304 STAINLESS STEEL WIRE SUPPORT MESH
MONOLITHIC CATALYST
CATALYST TEMPERATURE SENSOR
SECTION THRU CONVERTER

Figure 5-6. Monolithic Catalytic Converter

(Ref. 5-18). Presumably this involves the use of wire mesh and/or crimped wire located between the core and the canister.

A more recent addition is the use of a small pin extending through the stainless steel canister into the mesh which goes around the core element to prevent rotation of the core within the canister housing (Ref. 5-18).

5.4.2.4 Ford

Ford has tentatively selected the Engelhard PTX (noble metal/monolithic) catalyst for initial use, employing the American Lava ThermaComb substrate (Ref. 5-19). UOP, Matthey-Bishop, and W. R. Grace are other contending catalyst suppliers.

In all cases, it would appear that Ford would retain responsibility for production of the catalyst container. No details have been provided concerning canister design, materials, or ceramic core support techniques. In outward appearance, however, the design would resemble the Engelhard cylindrical PTX units.

Ford has also utilized test converters provided by Arvin Industries for pelletized catalysts. Arvin is also designing containers for monolith converter evaluations.

The Walker Manufacturing Company has also provided Ford with converters of the radial flow and downflow types for pelletized catalysts. Converter work with Walker is continuing.

5.4.2.5 Johnson-Matthey

Johnson-Matthey, in addition to producing noble metal/monolith catalysts has also supplied the converter outer shell or canister to the auto industry for limited test purposes (Ref. 5-13).

Johnson-Matthey originally produced a rectangular canister box containing two ceramic blocks, each 3-inches long. The canister had the edge seams welded. This type of catalyst core containment was discontinued due to weld seam cracking and attrition between the interfaces of the two ceramic blocks.

Johnson-Matthey now provides converters with the following design features.

a. Six-inch deep ceramic blocks

b. A ceramic tape cemented to the exterior of the catalyst block

c. A fire hardened cement at the periphery of the inlet and exist faces to prevent attrition on the securing frames.

d. Crimped wire mesh to secure the catalyst within the reactor to give a resilient mounting which compensates for the differential expansion of the ceramic/metal interface

e. A stainless steel reactor constructed by conventional muffler techniques in liaison with a UK exhaust system manufacturer

The ceramic core and container can be constructed in either cylindrical or oval cross section. The latest catalytic converter (AEC 3A), which is being evaluated on the Johnson-Matthey 1975 Concept Vehicle (see Section 5.7.6). is oval. Although Johnson-Matthey does not propose to supply such containers commercially, container designs and resultant characteristics are a part of the state-of-the-art technology.

5.4.2.6 Universal Oil Products

Universal Oil Products has developed a small cylindrical container for its pellet catalysts, the combination of which (container plus noble metal/pellets) is called the Mini-Verter (Ref. 5-9). It is similar to the Engelhard PTX container in shape; no design details are available.

5.4.2.7 Miscellaneous

As noted in Section 5.4.2.4, both Arvin Industries and the Walker Manufacturing Company have been and will continue working with the Ford Motor Company on catalytic converter development, primarily in canister or catalyst containment. Presumably these companies and others also cooperate with other automotive or catalyst companies and are a potential supplier of converter canisters.

5.5 CONTAMINATION AND DETERIORATION EFFECTS

A basic problem with catalysts, to date, is their unacceptable deterioration of conversion efficiency with mileage accumulation. This deterioration results from a variety of sources, including contamination effects and thermal and mechanical deterioration factors. The following sections summarize and discuss the more important considerations as disclosed by recent testimony and data submitted in support of the EPA Suspension Hearings.

5.5.1 Contamination Effects

5.5.1.1 Fuel Additives

There is universal agreement that the catalytic efficiency of current automotive catalysts can be lost or reduced by reaction with or blanketing by lead, phosphorus, and sulfur in gasoline. However there is a scarcity of actual test data to establish the actual poisoning mechanism and the particular amount of efficiency degradation attributable to a given contaminat level.

5.5.1.1.1 Lead Additives

With regard to lead additives, the early recognition of the deleterious effects on catalyst efficiency with accumulated mileage or test time (as reported in the recent Aerospace Corporation Lead Cost-Benefit Study, Ref. 5-20) resulted in the automobile companies conducting more recent catalytic converter evaluations with either lead sterile gasoline (less than 0.0002 gm/gal) or gasoline containing relatively low levels of lead (approx. 0.02 to 0.03 gm/gal). In response to this recognition and additional evidence concerning the deleterious effects of phosphorus, the Administrator of EPA has promulgated proposed rules (Ref. 5-21) to limit the lead content of gasoline to a maximum of 0.05 gm/gal and the phosphorus content to a maximum of 0.01 gm/gal; the maximum content of sulfur may be regulated upon submission of supporting evidence to establish the required level.

The actual lead levels used by the various companies differs widely, as shown in the following listing of test fuel lead levels.

a. AMC -- <.024 gm/gal (Ref. 5-22)

b. British Leyland -- 0.014 gm/gal (0.02 gr/gal in one occasion) (Ref. 5-23)

c. Chrysler -- 0.02 - 0.03 gm/gal (all tests to date) (Ref. 5-24)

d. Engelhard -- lead sterile (0.0002 gm/gal) and Amoco Premium (0.02 - 0.03 gm/gal) (Refs. 5-24 and 5-25)

e. Ford -- primarily 0.03 gm/gal (Ref. 5-19)

f. GM -- primarily 0.02 gm/gal (Ref. 5-16)

g. Matthey Bishop -- <0.0006 gm/gal (Ref. 5-13)

h. Saab-Scania -- 20 ppb (Ref. 5-26)

i. Toyota -- 0.01 -0.02 gm/gal (Ref. 5-27)

j. Volvo -- 0.015 gm/gal (recent vehicle tests) 5 ppm (some test fuels) 15 ppm (some bench tests) (Ref. 5-28)

k. VW -- 5-10 ppm (Ref. 5-29)

General Motors stated (Ref. 5-16) that tests were also made with gasoline containing 0.01 gm gal of lead, but GM could not notice much difference between these tests and those made with 0.02 gm/gal. Matthey Bishop (Ref. 5-30) reports that in a 100-hour static engine test run with 0.05 gm/gal there was only a very slight difference between "zero lead" (<0.0006 gm/gal) and 0.05 gm/gal. Chrysler (Ref. 5-24) believes that catalyst activity degradation with mileage varies directly with lead content at the lower levels (in the range of 0.05 gm/gal). Nissan (Ref. 5-31), in consonance with the Chrysler opinion above, feels that 0.01 gm/gal is preferable to 0.02 gm/gal.

It is evident, therefore, that the specific relationship between catalyst efficiency degradation and lead level is an elusive one. This is well illustrated by the Ford data of Figure 5-7, showing durability tests of an Engelhard PTX converter with ashless oil. As can be noted, although

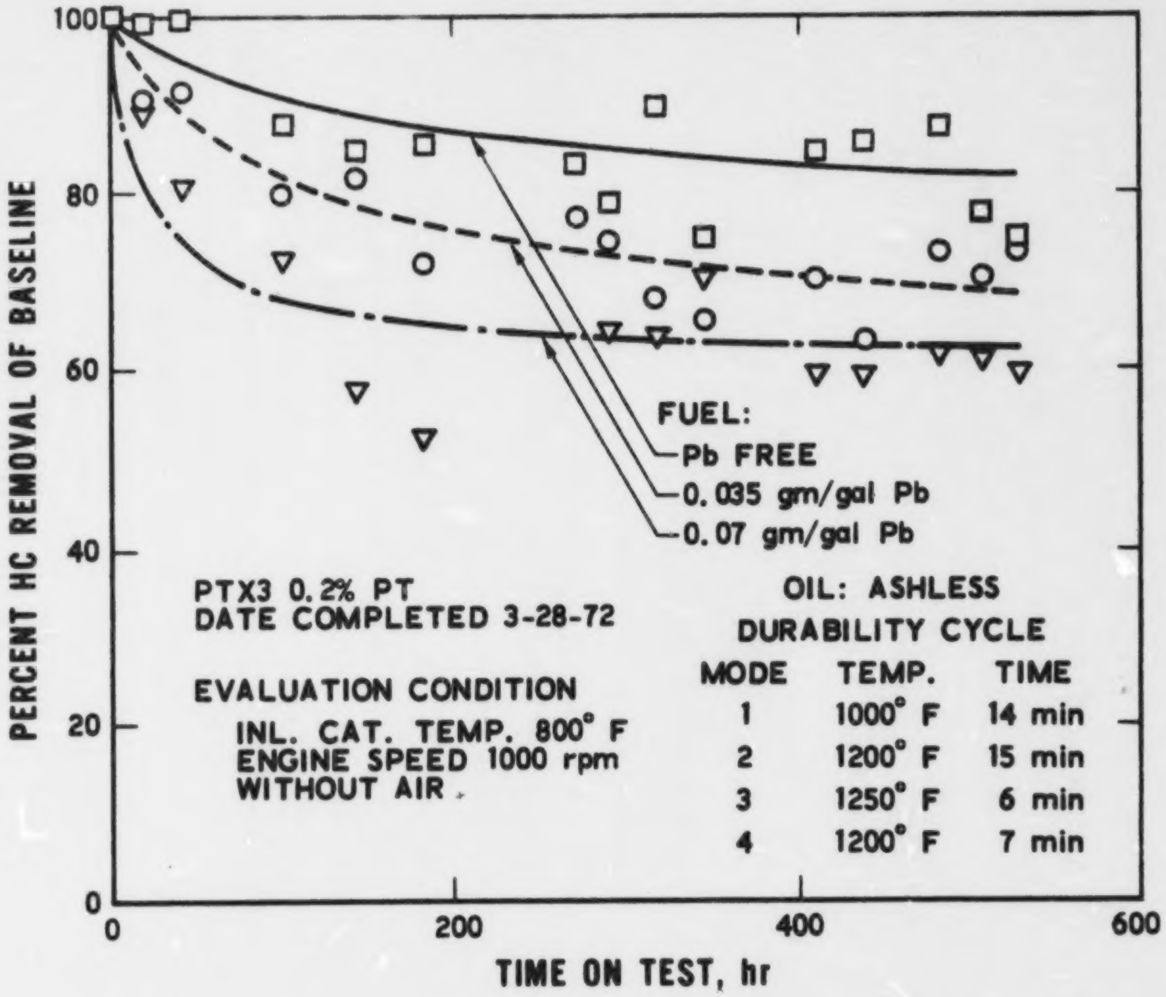


Figure 5-7. Effect of Lead Additive on Catalyst Efficiency

definite trends between the lead-free, 0.035 gm/gal, and 0.07 gm/gal levels can be established, variability in the data would make comparisons between discrete levels; e.g., between 0.01 gm/gal and 0.03 gm/gal; exceedingly difficult. Also, since these data were based on engine dynamometer tests run on nonrepresentive cycles, the relationships may not hold when mileage is accumulated on systems subjected to representative driving cycles. The conclusion that the lesser the amount of lead the better (within practical limits, of course) is an obvious one. Ford points out (Figure 5-7) that the catalyst HC efficiency decreases from 90 percent for the lead free case to 80 percent for lead levels as low as 0.03 gm/gal, and that this doubled the HC emissions for the Engelhard catalyst tested (Ref. 5-19).

While there may be some doubt as to whether the effect of lead is a "reactive" one or one of "mere coating" of the catalyst surface and pores, UOP has presented test evidence (Ref. 5-32) to illustrate that catalysts have a tolerance to occasional doses of lead (i.e., have a regenerative property). This is shown in Figure 5-8, showing lead effects on emissions for a car operated alternately on "lead-free" and leaded gasoline. During the early stages of the test, fuel was alternated between lead-free fuel with about 0.03 gm/gal and fuel containing 2.5 gm/gal lead. Catalyst recovery when operated on lead-free fuel is shown for both HC and CO emissions. At about 19,000 miles, the EPA's proposed regulation on fuels (Ref. 5-21) was published and the vehicle was switched to fuel containing 0.05 gm/gal lead and 0.01 gm/gal phosphorus. Catalyst activity, as indicated by the emission levels of HC and CO remained relatively constant over the balance of the 25,000-mile run.

Universal Oil Products ascribes this regenerative phenomenon to the opinion that the deleterious effect of lead is one of surface-covering and pore-clogging, not an irreversible chemical reaction. Further, UOP hypothesizes that there is an equilibrium-solution relationship between the engine exhaust gas and lead. With normal concentrations of lead (e.g. 2-3 gm/gal) the amount of lead is in excess of the amount the exhaust gas can accommodate (at the catalyst surface and gas temperatures existing in the converter) and therefore

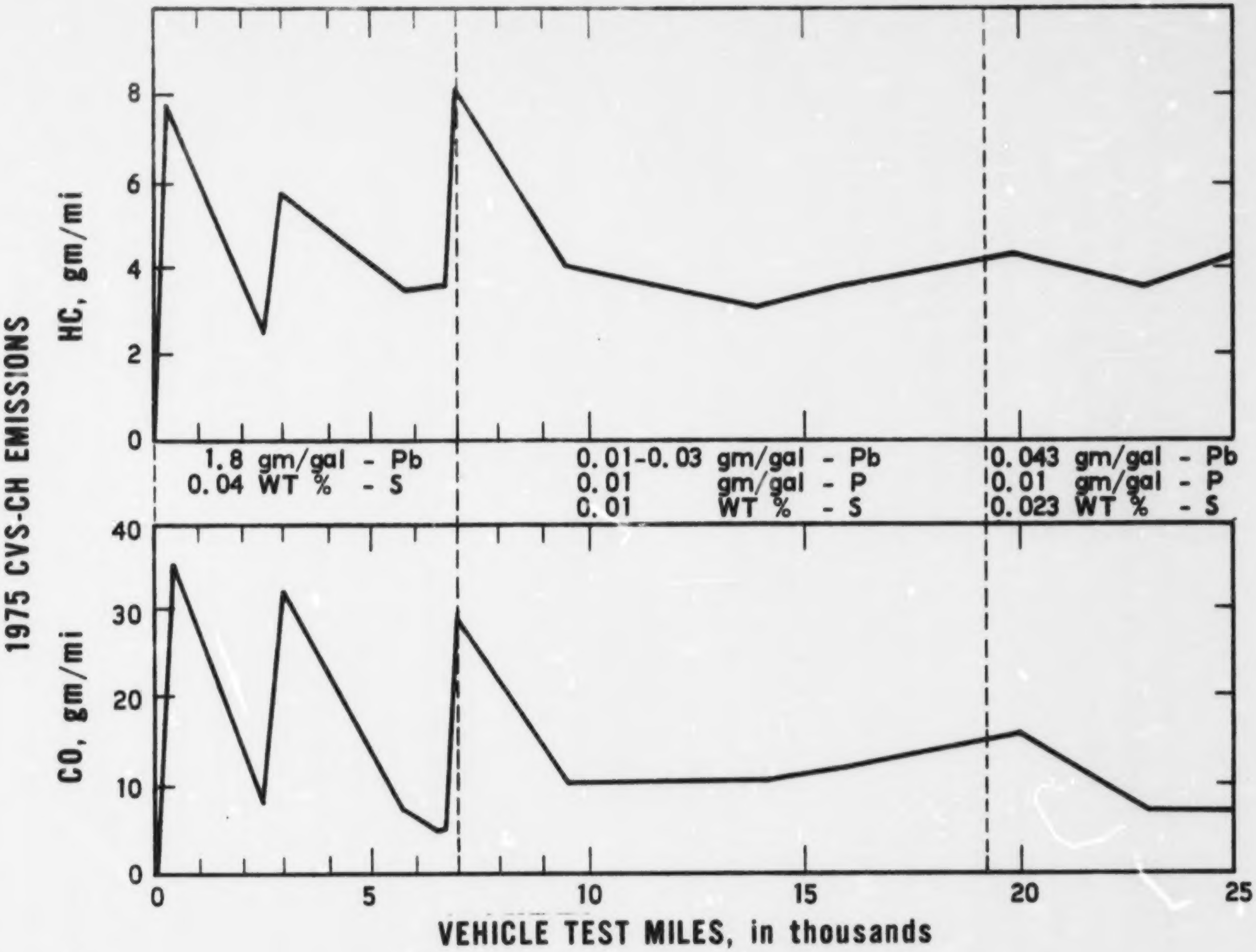


Figure 5-8. Lead Effects on Emissions During UOP 25,000-Mile Test

the lead deposits continuously out on the catalyst surface, thereby reducing its active surface area. Conversely, when the engine exhaust gas contains very low amounts of lead (e.g., approximately 0.03 gm/gal), the exhaust gas can accommodate more lead in solution and actually picks up lead volatized from the catalyst surface if it has been previously exposed to higher fuel lead concentrations.

Notice that this 25,000-mile UOP test was conducted on a noble metal/pelleted catalyst which may have operated at temperature levels somewhat higher than anticipated or used by the automobile manufacturers in some of their tests. It would be expected that the regenerative phenomenon disclosed by UOP data is temperature dependent; i.e., the higher the temperature the lower the lead deposition rate (with leaded fuels) and/or the higher the lead vaporization rate from catalyst surfaces.

Therefore, engine systems designed to minimize "raw" exhaust emissions entering the catalytic converter (lower HC and CO, lower inlet gas temperatures) would appear to be more adversely affected by lead concentrations in the fuel than engine systems designed to rely on the catalytic converter for more HC and CO oxidation (higher HC and CO levels to converter).

With regard to pellets versus monolithics, Oxy-Catalyst (Ref. 5-7) indicates its experience reveals that pellets are more resistant to lead (and other contaminants) than monolithics. Oxy-Catalyst OC-100 purifiers (using platinum pellet catalysts) operate effectively for at least 300 hr on regular leaded gasoline while its monolithic or honeycomb type of purifier is rendered quite ineffective after only 25 to 50 hours of operation on the same gasoline.

5.5.1.1.2 Phosphorus and Sulfur Additives

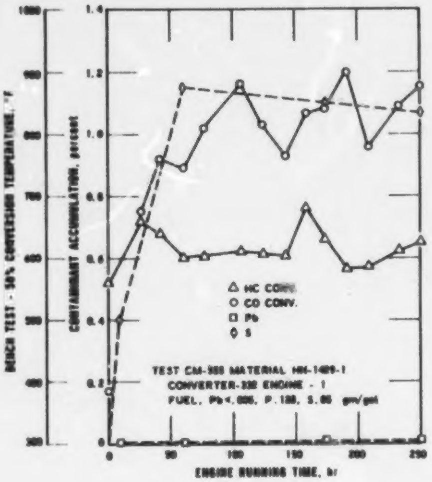
Much less specific information is available concerning the deleterious effects of phosphorus and sulfur on catalytic activity. Saab-Scania (Ref. 5-33) reports "catalyst poisoning" with fuel containing only 4 ppm phosphorus. The fuel used in this test had only 20 ppb of lead.

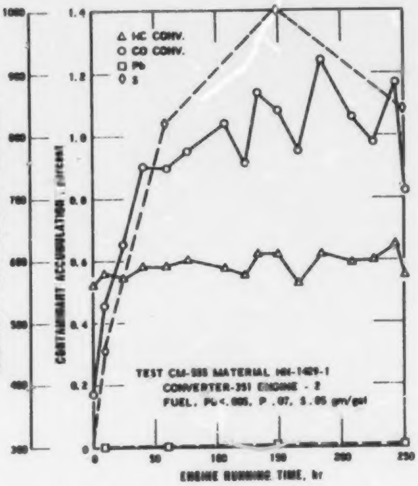
General Motors tests (Ref. 5-16) have been conducted with 0.02 gm/gal Pb, 0.005 gm/gal phosphorus and 0.03 percent sulfur. It has seen no "significant" differences in the effects of these contaminants on base metal catalysts as opposed to noble metal catalysts. General Motors feels that lead may be worse for base metals, but it cannot prove it. General Motors states (Ref. 5-34) that if a vehicle is driven with a catalytic converter at temperatures of 900-1200°F (where GM's operates most of the time) this is a temperature range where sulfur readily deposits on the catalyst surface. If the converter could be designed to operate above 1300°F all the time, then sulfur problems would be alleviated. General Motors feels that phosphorus effects are bad regardless of the converter operating temperature (inferring an irreversible reactive poisoning effect).

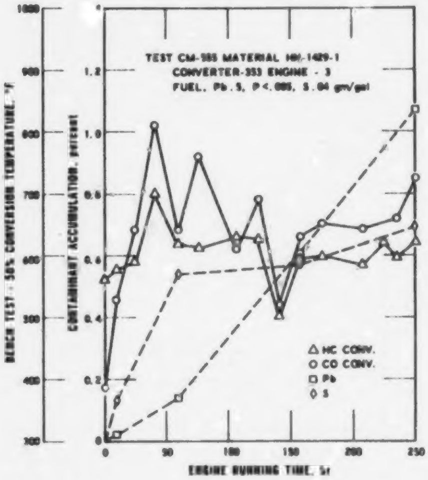
Oxy-Catalyst (Ref. 5-7) has provided GM bench test data of their base metal/pellet catalyst material HN-1429-1. These data on conversion temperature and contaminant buildup vs engine running times are shown in Figures 5-9, 5-10, 5-11, 5-12, 5-13, and 5-14, and illustrate the effects of varying contents of lead, phosphorous and sulfur in the test fuel. While interactions are possibly involved, the data indicate that sulfur buildup on the catalyst appears to be especially damaging to carbon monoxide reactivity. This effect is described in the figures as the increase in the 50-percent conversion temperature, or "light-off" temperature, with endurance or running time. Increase in "light-off" temperature causes increase in emissions when tested under cold start conditions. These figures also indicate the build-up of lead on the catalyst with increasing lead content, as discussed above in Section 5.5.1.1.1. No clear phosphorus effects are noted on the figures for the concentrations tested.

5.5.1.2 Oil Additives and Miscellaneous Effects

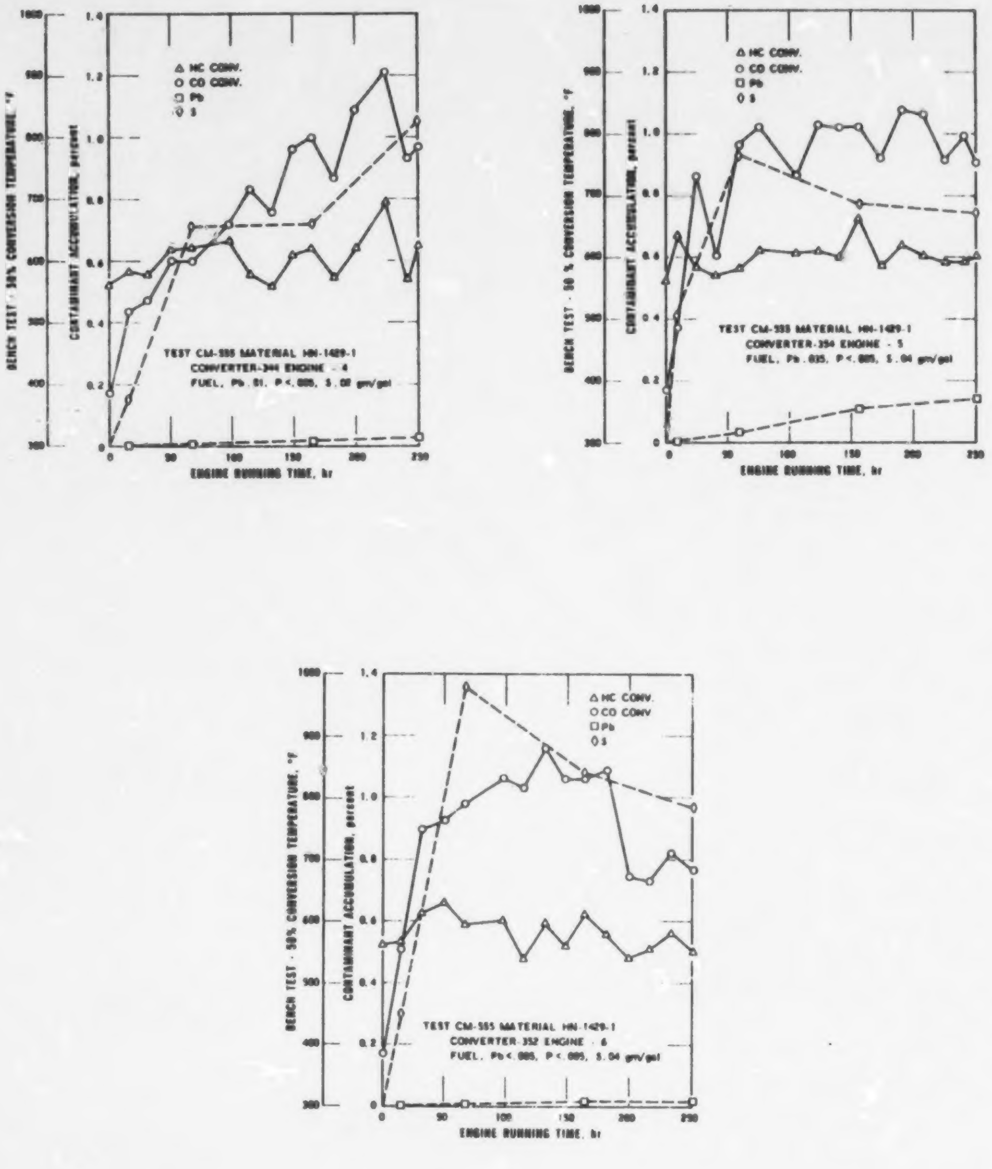
A recent chemical analysis by Ford (Ref. 5-35) of a catalyst which had been durability tested revealed contamination from the following sources: lead and phosphorus from fuel and lubricants; zinc from lubricants; copper from an unknown source; and nickel, chromium, iron and manganese from the reactor







Figures 5-9, 5-10, 5-11. Oxy-Catalyst Fuel Effects Data



Figures 5-12, 5-13, 5-14. Oxy-Catalyst Fuel Effects Data manifold liner. Ford feels that further work must be done on reducing contaminant levels in fuels and lubricants. The metal contaminants are of particular concern since they could have a serious bearing on the suitability of a reactor/catalyst combination.

Engelhard has reported a 50,000-mile durability test for their PTX catalyst (Ref. 5-36). The test was conducted with an unleaded gasoline having a lead content of approximately 0.03 gm/gal. The catalyst picked up substantial quantities of Pb, Zn, P, and Ba during the test. The Zn and Ba are contaminants that Engelhard associates with motor oil. Engelhard's present position is that the most probable cause of PTX catalyst deterioration are metal poisons that may be present in the fuel and lubricating oils.

Matthey Bishop expressed the opinion (Ref. 5-30) that the HC efficiency deterioration of their catalyst was due to phosphorus pickup from the engine oil.

5.5.2 Deterioration Effects

5.5.2.1 Thermal Effects

5.5.2.1.1 Alumina Phase Changes

Automotive catalyst pellet substrates are composed of activated alumina material, as noted in Section 5.2.2. Monolithic substrates also have a wash-coat of alumina (or promoted alumina) on the honeycomb ceramic substrate to provide the porosity and high surface area to volume characteristics essential for high catalytic activity.

Although the alumina (pellet or monolith wash coat) does not melt until a temperature of approximately 3600°F is reached, it does undergo a phase change from gamma alumina to alpha alumina at approximately 1750°F. Chrysler states that the effect is one of crystal agglomeration which reduces the porosity of the alumina to a point where the catalyst reactivity is significantly reduced. Chrysler states that such an overtemperature exposure of only from 1 to 2 seconds is sufficient to result in significant catalyst deactivation (Ref. 5-24).

5.5.2.1.2 Thermal Shrinkage

Pellet substrates (alumina) are also subject to shrinkage in physical volume with increased temperature. The effect of such thermal shrinkage is to reduce the catalyst efficiency via reduced surface area and to cause a "loosening" of the pellets in the converter canister (in the absence of mechanical design features which compensate for the volume loss).

General Motors reported that in early designs excessive shrinkage occurred at a temperature of 1400°F. It feels that current pellets exhibit satisfactory thermal shrinkage properties at temperatures up to 1800°F. General Motors' current pellet specifications allow 10-percent shrinkage when exposed to 1800°F for 24 hours (Ref. 5-34).

5.5.2.1.3 Thermal Differential Expansion

Both pellet and monolithic substrates have thermal expansion coefficients different from the converter canisters housing them. Upon bed warm-up, the pellets can become looser in the bed than originally packed. Monolith catalyst elements also can become "loosened" with respect to the container. Both may then be subject to mechanical attrition effects as discussed in Section 5.5.2.2.

5.5.2.1.4 Melting

Although the alumina material (pellet and wash coat of monolith) does not melt until about 3600°F, the cordierite material used for monolithic substrates (e.g. American Lava ThermaComb and Corning W-1) has a melting point of approximately 2500-2600°F. Even though the overall bed temperature is below this level, local zones have been subject to overtemperature conditions and have melted. Engelhard reports (Ref. 5-18) that this is a self-limiting phenomenon in that it is local in nature and does not affect the overall monolith or the canister metal. Toyota (Ref. 5-37) also refers to monolith melting damage due to local overtemperatures. American Lava (Ref. 5-38) confirms the partial internal melting characteristic which reduces the overall catalyst efficiency but does not necessarily "fail" the entire unit.

A related problem with regard to pellet catalysts is referred to by UOP (Ref. 5-39). There have been instances wherein pellet catalyst have been exposed to overtemperature conditions to the point where the pellet retaining outlet screen burned out (screen melts at 2600°F). The result was that the catalyst pellets blew out the tailpipe; however, they were cool enough to handle by the time they left the tailpipe. Also, Nissan (Ref. 5-31) refers to a test in which a pellet catalyst (of Japanese manufacture) "burned and stacked together (fused)" under conditions of full-load at 60 mph.

5.5.2.2 Vibration Effects

The catalytic converter is subjected to vibratory inputs from a number of sources, including road shocks, induced mechanical loads from mounting to the engine exhaust system (exhaust manifold and/or pipe extending therefrom), and gas dynamic loads from the pulsating exhaust gas flow.

With regard to induced mechanical loads there is some evidence that second-order rotational vibrations associated with 4-cylinder in-line engines may be more severe than 6-cylinder or V-8 engines.

5.5.2.2.1 Pellet Catalysts

In pellet catalysts the principal effects of excessive vibratory forces are pellet breakup or "attrition". Volvo (Ref. 5-40) reports that in a test run in March 1972 with an AC-Delco converter the pellets broke up and resulted in an empty container in approximately 5000 miles. Volvo had similar pellet breakup with UOP noble metal catalysts. Toyota and Mercedes-Benz (Daimler) (Ref. 5-41) report similar pellet rupture experience. Chemico (Ref. 5-3) indicates that pellet attrition requires refill or topping off in approximately 3000-mile intervals for their current design to maintain 1975 emission levels. They project refill intervals of approximately 8000 miles for an advanced design.

On the other hand, GM (Ref. 5-16) states that it currently has no physical durability problems with their pellet catalysts. It acknowledges pellet attrition problems prior to early 1970, but claims its converter design has solved the problem.

5.5.2.2.2 Monolith Catalysts

Nearly all monolith catalysts tested to date have utilized American Lava substrates of either the spiral (rolled) or stacked (parallel-layered structure) types as shown in Figure 5-2. Originally, stacked type designs were utilized; then the spiral type was used. Current monoliths with American Lava substrate are of the stacked type because of severe mechanical cracking problems with the spiral type. Monolithic catalysts were originally cylindrical in cross-section; however, oval shapes are also being evaluated.

Volvo (Ref. 5-42) reports a number of monolith mechanical failures, especially in conjunction with 4-cylinder engine operation. This failure mode is attributed to characteristically high second-order rotational vibratory forces. Three Johnson-Matthey oval converters have failed mechanically in low-mileage tests at Volvo. One of these broke in pieces at 700-800 miles. Volvo's longest durability test to date (with an Engelhard PTX unit) was recently ended at 29,900 miles with a failure of the substrate. The substrate was extruded out of the converter housing; there was no indication of overheating (Ref. 5-28).

VW (Ref. 5-29) feels that the principal cause of mechanical failure of spiral and stacked monolithic substrates is the differential thermal expansion between the substrate and the container housing which then allows the vibrating movements between the ceramic core and the housing. Saab-Scania (Ref. 5-26) concurs in this regard. American Lava (Ref. 5-38) feels that the spiral type of substrate is more susceptible to this type of damage; this is why it has reverted to the stacked substrate design.

In an early converter design in which two [end-to-end] ceramic pieces were used to comprise the catalyst core, Johnson Matthey reports that movement between the two pieces resulted in mechanical failure (Ref. 5-30).

Chrysler (Ref. 5-17), GM (Ref. 5-16), and Daimler-Benz (Ref. 5-41) also report mechanical failure problems with monolithic substrates.

Engelhard (Ref. 5-18) claims to have solved the monolithic differential thermal expansion problem with a patented proprietary design (including wire mesh between ceramic and container). Matthey Bishop (Ref. 5-13) claims the problem is solvable by use of improved support materials, insulation between the ceramic and the canister, and crimped wires between ceramic and the canister.

5.6 PRINCIPAL PROBLEM AREAS AND PLANS FOR RESOLUTION

Based on the information discussed in Section 5.5, it would appear that the primary problem areas associated with the use of oxidation catalysts include catalyst contamination, inadequate catalyst activity, thermal deterioration, and catalyst attrition.

The following sections discuss each of these basic problem areas and indicate the plans underway or proposed for resolving them. Notice that the automotive catalytic converter technology is rapidly changing as a result of intensive product design, test, and evaluation programs in both the catalyst supplier and automotive industries. Therefore, the activity and durability data reported by various companies as their latest results are based often on catalyst materials and substrates which may be in fact old technology previously discarded by others. Due to the time-lag inherent in the relationship between the substrate-catalyst-converter suppliers and the auto makers themselves, it is natural that some instances reported as "severe problems" by one company are treated as "solved problems" by others.

5.6.1 Contamination Control

As mentioned in Section 5.5.1.1, the Administrator of EPA has proposed (Ref. 5-21) to limit the lead content of gasoline to 0.05 gm/gal and the phosphorus content of gasoline to 0.01 gm/gal for the unleaded grade of gasoline to be made available for automobiles utilizing catalytic converters. A similar regulation of the sulfur content in such unleaded grade will also be promulgated if the auto companies can present substantive evidence to establish the needed level.

All parties agree that zero levels of contaminants would be desirable, but practical considerations such as lead contamination in shipment, and the need for phosphorus additives used in detergent or carburetor cleaning solutions, dictate that trace levels of these contaminants will have to be "tolerated" by the catalysts, at least in the immediate future.

The exact contribution of lubricating oil constituents to catalyst deactivation is not evident. Ashless oils would certainly help to assure minimization of this contaminant but such oils have not been widely evaluated and could adversely affect other engine parts. At present there is no clear picture of whether or not to regulate lubricating oil composition. Therefore it would appear that near-term automotive catalysts would have to "tolerate" conventional lubricating oils.

5.6.2 Increased Catalyst Activity

An obvious approach to improving the ability of emission control systems with oxidation catalysts to meet the 1975 standards is to increase the catalyst activity. This is particularly true with regard to lowering the light-off temperature, inasmuch as the sooner after startup that the catalyst is active the lower the cold start emissions. It would be expected that all catalyst suppliers would be actively pursuing such technological advancements to gain a competitive advantage.

For example, in this area Engelhard (Ref. 5-4) has recently related progress in improving the catalytic activity and thermal stability of PTX-type monolithic catalysts. Overall progress is demonstrated in Figure 5-15 where all catalysts shown were thermally aged and evaluated in a bench scale adiabatic catalyst screening unit. Comparison of data for standard versus improved PTX show the improved PTX catalyst has greatly increased retention of activity for CO and olefinic hydrocarbon oxidation even after severe thermal aging.

Johnson-Matthey (Ref. 5-13), another proponent of noble metal/monolith catalysts, also has reported similar progress in improved catalytic activity and high temperature thermal stability. For example, Figure 5-16 illustrates the low light-off temperature characteristics of its most advanced catalyst, AEC 3A, and compares it to some of their other noble metal/monoliths and a base metal (copper chromite) catalyst. The effects of thermal aging on the AEC 3A catalyst are shown in Figure 5-17. As can be noted, the effects are similar to the "improved PTX" characteristics of Figure 5-15 in terms of the 50-percent conversion temperature. The figure shows that exposure to elevated temperatures increases the catalyst light-off temperature. After aging at 970°C (1778°F) the 50-percent conversion (or light-off) temperature is approximately 275°C which compares to a 50-percent conversion temperature of approximately 280°C for the Engelhard improved PTX catalyst when exposed to the same aging temperature (Figure 5-15).

General Motors, currently a base metal/pellet proponent, confirms the basic difference in activity characteristics between base and noble metal catalysts. However, GM (Ref. 5-34) points out that the base metal catalyst starts conversion at very low temperatures and the level of conversion gradually increases as temperature increases. This is shown in Figure 5-18. On the other hand, the noble metal catalyst does little conversion until a threshold temperature is reached. The conversion characteristic of the base metal at lower temperatures can be an advantage if the application results in temperatures in the lower range.

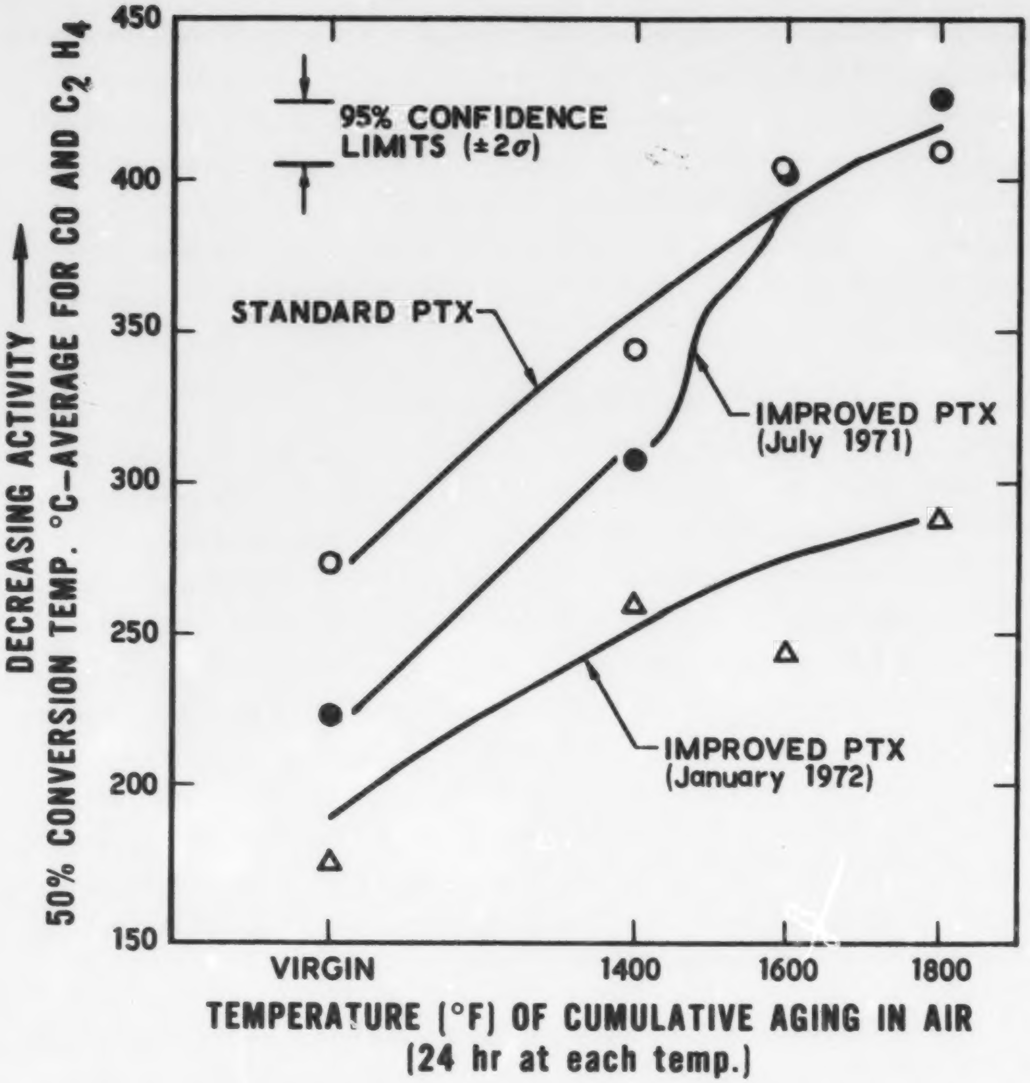


Figure 5-15. Progress In Development of Monolithic Catalysts With Improved Catalytic Thermal Stability

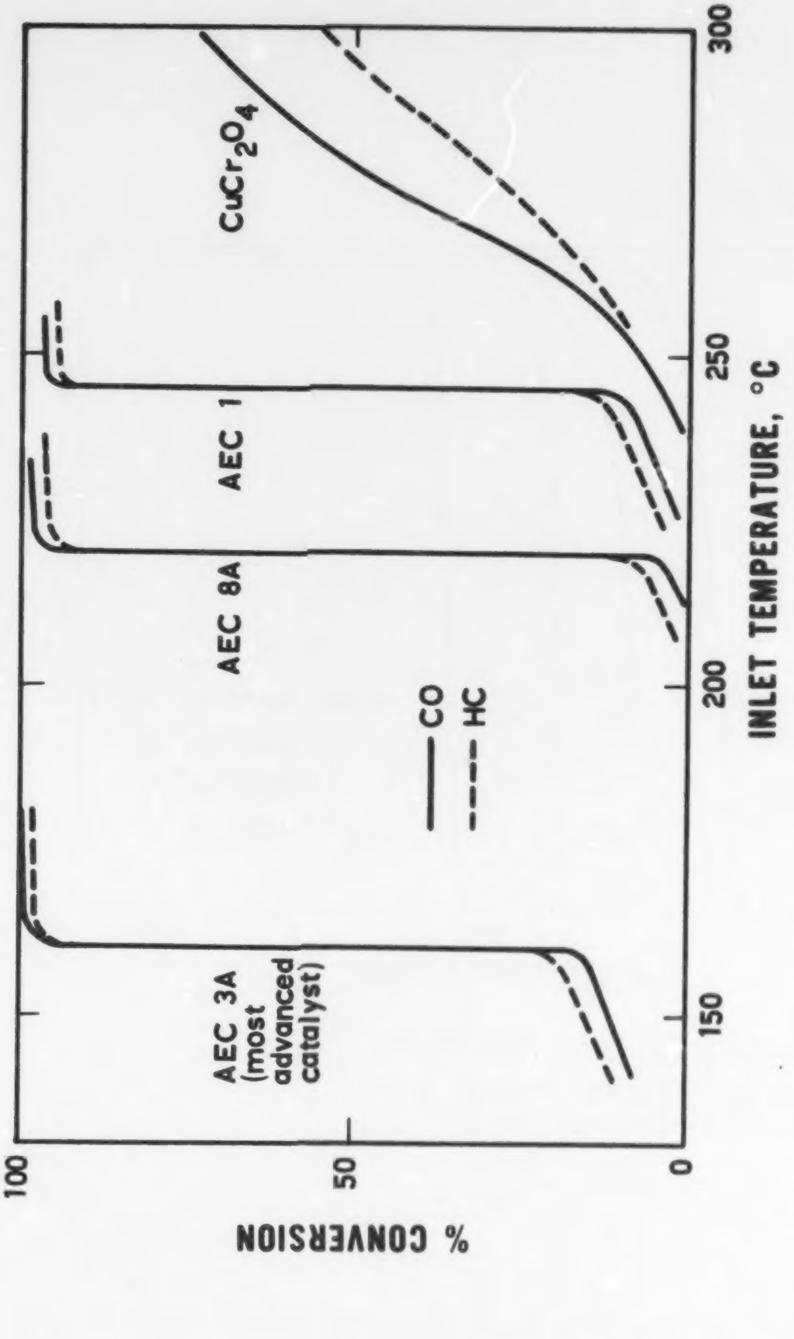
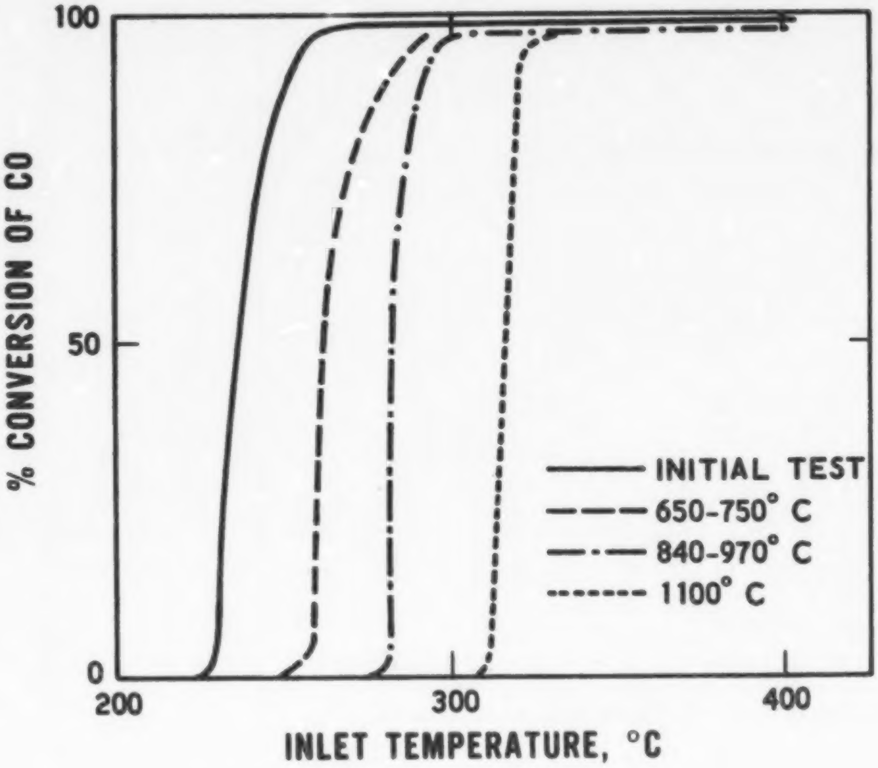


Figure 5-16. Johnson Mathey Catalyst Light-Off Temperatures



STATIC ENGINE DURABILITY TEST:
EFFECT OF TEMPERATURE OVER
A 24-hr TEST ON AEC 3A

Figure 5-17. Effects of Thermal Aging on AEC3A Catalyst

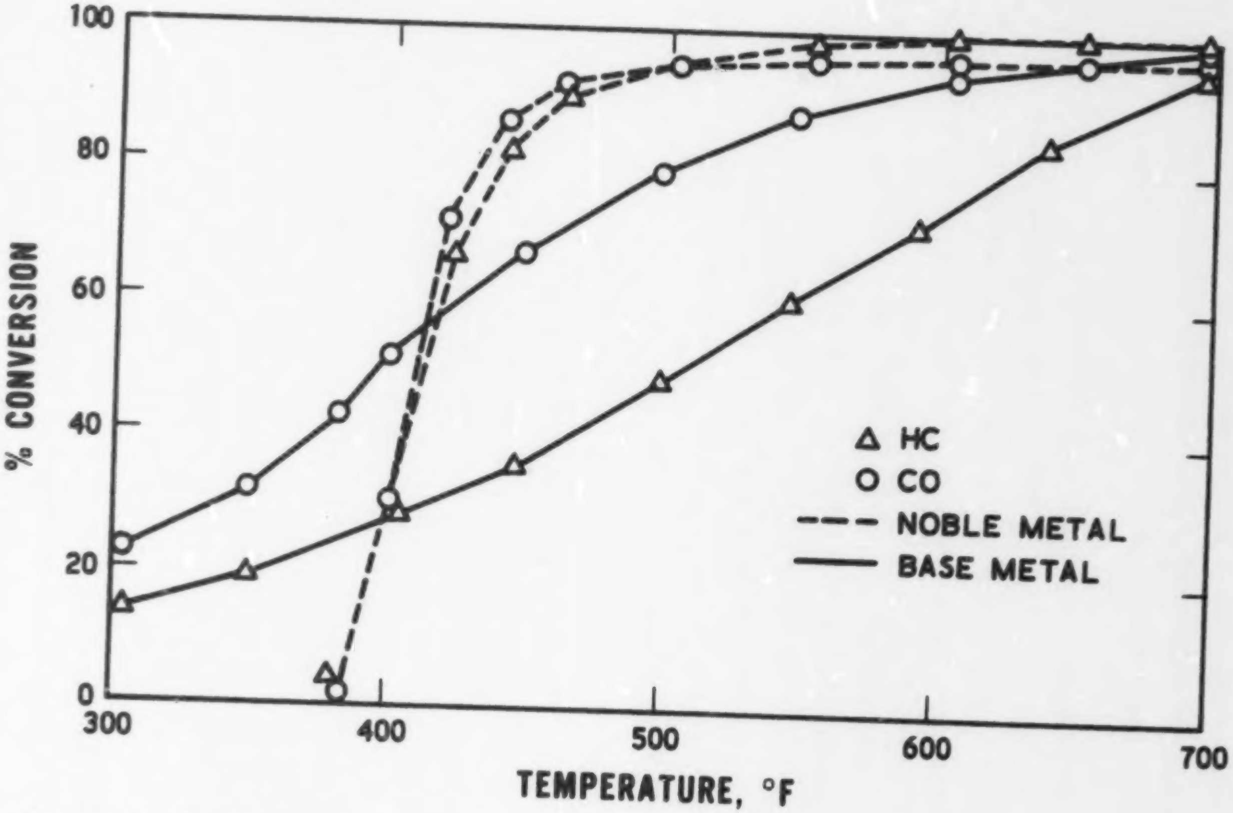


Figure 5-18. Conversion Characteristics of Base Metal and Noble Metal Catalysts (Standard Bench Test Evaluation)

General Motors also presented data to show how prolonged exposure to elevated temperature affects catalyst activity toward hydrocarbons and CO. Figure 5-19 shows how a typical noble metal catalyst deteriorates when subjected to temperatures in the range of 1200 to 2000°F.

Figure 5-20 shows similar data for a typical base metal catalyst. In the temperature range between 1200 and 1500°F, there is no significant increase in the 50-percent conversion temperature and so there is no significant deterioration in catalyst activity if this temperature range is not exceeded.

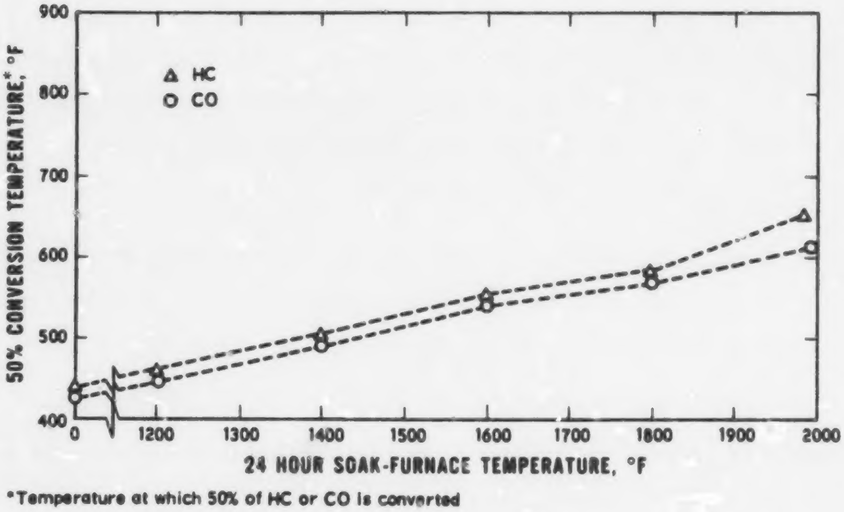
General Motors concludes that these characteristic differences can be optimized for either catalyst type. In GM's system application, considering cold start engine operation and catalyst operation at lower temperatures, these differences tend to be optimized in favor of the base metal catalyst. With a different physical application of the catalyst, the advantages of the noble metal catalyst could be optimized.

5.6.3 Thermal Control

Thermal control devices or techniques are required to protect the catalyst and provide for vehicle safety. The catalyst protection is required to prevent thermal-associated activity degradation and durability degradation. The vehicle safety requirement involves protection against overheating problems which might result in vehicle fires or external fires caused by contact with hot catalytic converter surfaces. Most devices or techniques which protect the catalyst also provide for vehicle safety. However, some vehicle safety provisions (e.g., heat shields between converter and body floor) do not aid in catalyst protection. Thermal control devices or techniques are separately discussed in Section 5.8.

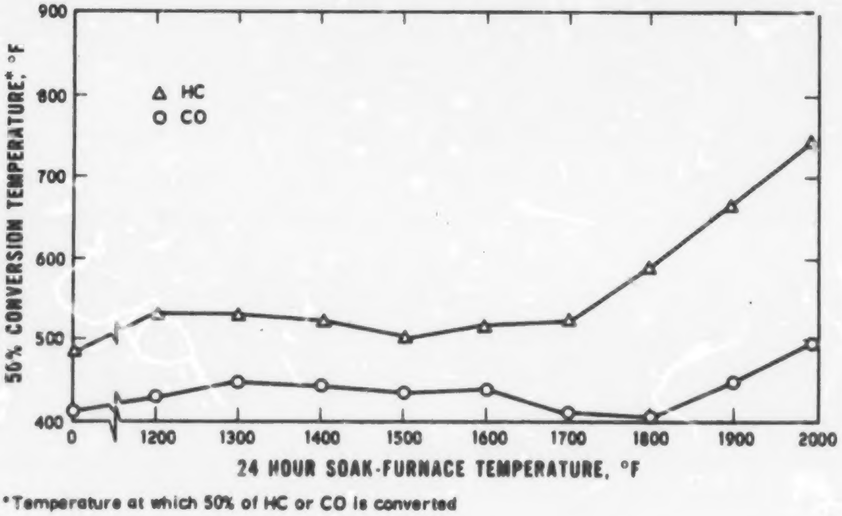
5.6.4 Attrition Control

Advances in both catalyst substrate properties and canister design features are required to meet the durability requirements of the 1975 emission standards.



*Temperature at which 50% of HC or CO is converted

Figure 5-19. Soak Temperature Effects on Catalyst Activity (Noble Metal Catalyst)



*Temperature at which 50% of HC or CO is converted

Figure 5-20. Soak Temperature Effects on Catalyst Activity (Base Metal Catalyst

5.6.4.1 Substrate Properties Improvement

Early pellet substrates were subject to severe breaking-up or attrition as well as thermal shrinkage problems. As evidenced by GM's (Ref. 5-34) current specification requirements (10-percent shrinkage for 24 hours at 1800°F) and American Cyanamid's statement (Ref. 5-43) that they have "whipped" the 1800°F and attrition problem, substantial improvements in pellet attrition durability characteristics have already been achieved. Further improvements may be possible.

Similarly, the improved catalyst properties described by Engelhard (Section 5.6.2) leading to increased high-temperature activity, may result in improved durability of the alumina wash coat of the monolith catalyst.

5.6.4.2 Canister Design Features

The wide spectrum of catalytic converter mechanical failure types and modes shown in Section 5.5.2.2 illustrate clearly that the canister (or container) design must protect the ceramic substrates (pellet or monolith) from excessive vibratory loads and stresses. In view of the inherent fragility of ceramics, such failures can be ascribed to deficiencies in the canister support design.

5.6.4.2.1 Pellet Converters

Aside from GM (AC-Delco) and UOP (Mini-Verter), most companies had exceedingly poor results with pellet converters. For example, Chemico (Ref. 5-3) requires pellet addition (due to attrition) at 3000- to 8000-mile intervals.

General Motors (Ref. 5-16) claims that its horizontal-bed converter design, in combination with thermal shrinkage improvements in the pellet substrate, has solved the attrition problem. If so, its internal pellet support arrangement (top and bottom retaining screens, etc.) is such as to accommodate relative thermal expansions of pellets, retainers, and canister shell while holding the pellets in sufficiently close-packed proximity to prevent vibratory movement of the pellets against each other.

5.6.4.2.2 Monolith Converters

Early monolith converters apparently were little more than a sheet-metal canister housing the ceramic core. In such an arrangement it would be expected that differential thermal expansion and vibratory loads would severely damage the catalyst, as has been evidenced.

A number of promising design approaches, however, have been advanced for solving these problems. For example:

a. Engelhard has a potential proprietary method of compensating for the differential thermal expansion between the ceramic core and the stainless steel canister (wire mesh between them). It also has provided a pin (extending through canister and wire mesh) to prevent axial movement between core and canister. (Ref. 5-18).

b. Volkswagen has proposed a spring-loaded sleeve between the core and canister. (Ref. 5-44).

c. Volvo has proposed the use of rubber mounts for the converter. (Ref. 5-42).

d. Johnson-Matthey (Ref. 5-13) claims the problem is solvable by use of improved support materials, insulation between ceramic and the canister, and crimped wires between the ceramic and the canister.

5.7 EMISSIONS

The following sections summarize pertinent results as to the emission characteristics of the various catalysts proposed for use. No attempt is made to summarize all of the existing data; rather, the approach used is to select those data considered most representative of the current state of the art of automotive oxidation catalyst technology.

5.7.1 Air Products and Chemicals (Houdry Division)

Houdry has submitted base metal/ pellet catalysts to General Motors, Chrysler, and other automotive companies. Houdry does not perform vehicle emission tests and therefore relies on auto company data, (Ref. 5-1).

5.7.1.1 Low Mileage Emissions

Tables 5-6 and 5-7 indicate the properties of four catalysts supplied to GM (Ref. 5-1) and two catalysts supplied to Chrysler (Ref. 5-1) together with low mileage emission data as provided by the auto companies to Houdry. Notice that all six catalysts were well below the 1975 HC standard, but two catalysts exceeded the CO standard, even at low mileage.

5.7.1.2 High Mileage Emissions

An early Houdry catalyst was evaluated in a 50,000-mile durability test by AC but demonstrated declining performance (Ref. 5-1). The results of this evaluation are shown in Figure 5-21. It was discovered at the conclusion of the test that 40 percent of the volume of the catalyst and 20 percent of the initial weight had been lost, indicating substantial shrinkage and attrition. It was not until the fall of 1971 that catalysts with sufficient physical strength has been prepared by Houdry to justify extensive durability tests by AC. The results of these later AC durability tests and of Chrysler durability tests are not yet available to Houdry.

5.7.1.3 Comparison with Auto Company Data

Pertinent recent test data from General Motors (Ref. 5-45) and Chrysler (Ref. 5-17) are shown in Table 5-8. Notice that no tests at extended mileage meet the 1975 standards.

Table 5-6. Emission Data From Air Products and Chemicals Corp. (Houdry)[a]

	Catalyst A	B	C	D
50% conversion fresh condition				
CO (°F)	402	390	402	421
HC (°F)	442	423	418	424
50% conversion 1800°F-24 hr. aging				
CO (°F)	407	443	470	438
HC (°F)	664	598	565	467
Shrinkage after 1800°F 24 hr. aging, vol. %	18.4	5.0	3.2	2.0
Attrition after 1800°F 24 hr. aging, wt. % loss	8.7	2.7	2.3	1.5
Car Test Results (AC)				
1975 CVS-CH Emissions				
HC, gm/mi	0.27	0.32	0.28	0.30
CO, gm/mi	3.3	3.2	3.3	3.8

[a] Catalysts supplied to AC Div. of GM (Ref. 5-1)

Table 5-7. Emission Data From Air Products and Chemicals Corp. (Houdry)[a]

	Catalyst E			F	
50% conversion fresh condition					
CO (°F)	396			390	
HC (°F)	454			423	
50% conversion 1800°F-24 hr. aging					
CO (°F)	355			443	
HC (°F)	359			598	
Attrition after 1800°F 24 hr. aging, wt.% loss	3.6[b]			2.7[c]	
Chrysler dynamometer test (Car 259) gm/mi	Run No.	HC	CO	HC	CO
	(73)	0.23	3.6	0.26	3.4
	(74)	0.20	2.8		
	(75)	0.28	4.9		
	(76)	0.20	3.6		
	(77)	0.19	3.5		
	(78)	0.17	3.6		
	Avg.	0.21	3.65		

[a] Catalysts submitted to Chrysler Corp. (Ref. 5-1)

[b] 1700°F-16 hr. aging

[c] 1800°F-24 hr. aging

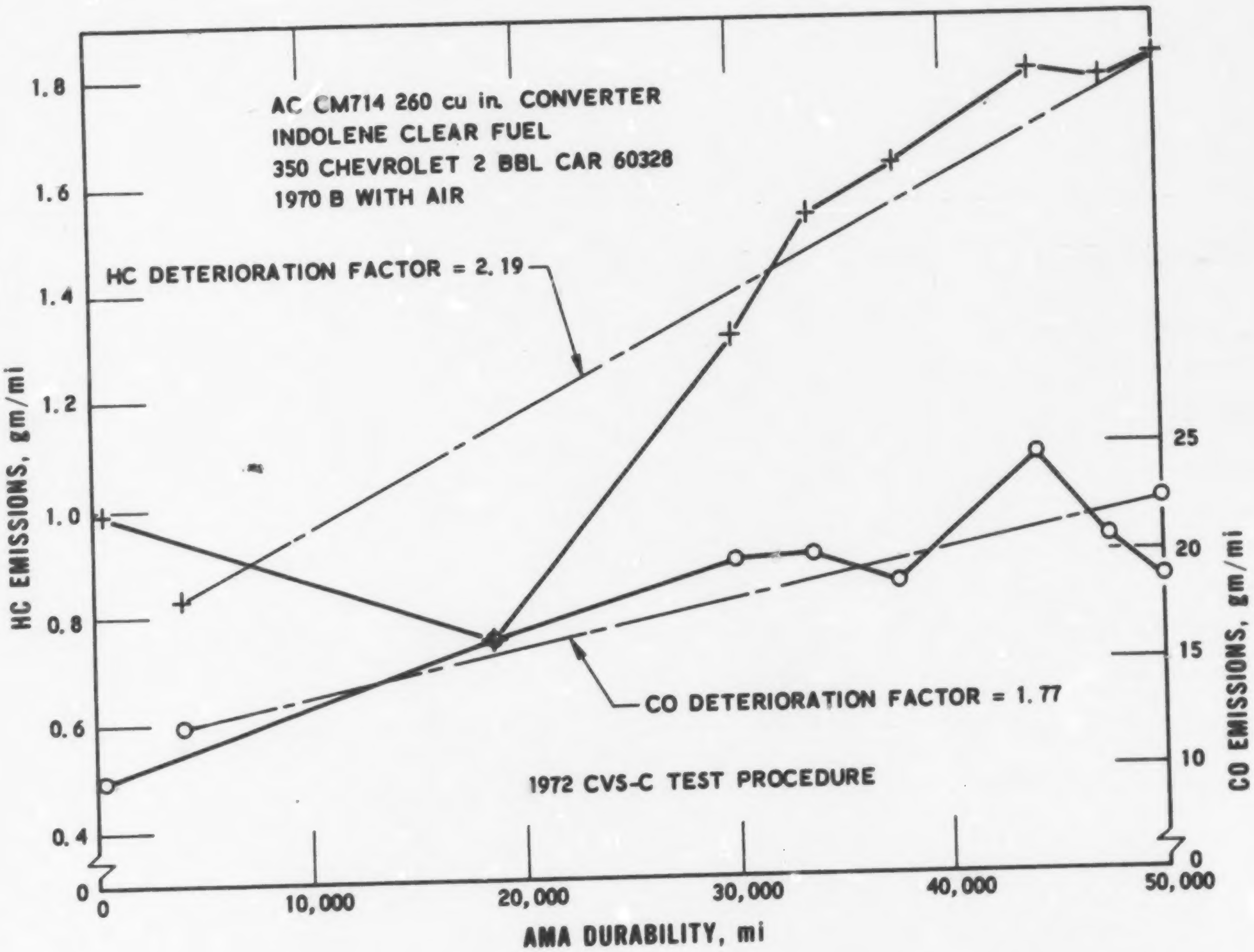


Figure 5-21. Durability Data for Houdry Base Metal Catalyst HN 1269

Table 5-8. APCC (Houdry) Catalysts (Auto Co. Data)

Car No.	Car and/or CID	Test Weight	Test Date	System Description						CVS Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
Chrysler															
259	360			x	x	x		30% Size	Base/Pellet (1057 JX8-2X1)	1972	0 170	0.23 0.17	3.6 3.6	1.21 1.83	
GM															
62403	Oldsmobile 455	5000	2/72	x	x	x			Base/Pellet (1259 JX3-1X1)	1975	118	0.45	5.4	1.0	System Development
62411	Oldsmobile 455	5500	1/72	x	x	x			Base/Pellet (1259 JX3-1X1)	1975	240	0.52	5.0	0.9	System Development
62102	Buick 455	5500	2/72	x	x	x	x		Base/Pellet (1259 JX3-1X1)	1975	1,689	0.63	3.2	1.0	System Development
62115	Skylark 455	4500	4/72	x	x	x	x		Base/Pellet (1259 JX3-1X1)	1975	280	0.70	2.5	0.9	System Development
61203	Cadillac 472	5500	2/72	x	x	x			Base/Pellet (1259 JX4-1X1)	1975	300	0.25	6.0	0.9	System Development
61322	Chevrolet 350	4500	2/72 3/72	x	x	x			Base/Pellet (1259 JX3-1X1)	1975	0 1,158	0.44 0.66	3.2 10.3	0.2[a] 0.2[a]	Catalyst changed; Excessive Deterioration
61318	Chevrolet 350	4500	12/71 4/72	x	x	x			Base/Pellet	1975	0 21,178	0.25 0.87	2.9 4.1	1.9 1.6	Test continuing
62505	Pontiac 455	4500	2/72 2/72 4/72 4/72	x	x	x	x		Base/Pellet	1975	6 1,465 1,914 3,778	0.22 0.57 0.36 0.53	0.9 2.4 1.3 1.75	1.4 1.4 1.1 1.0	Discontinued; high deterioration
2586	Oldsmobile 350	5000	2/72 3/72	x	x	x			Base Pellet (1259 JX3-1X1)	1975	42 1,168	0.28 0.71	7.3 12.5	3.7 3.8	Overtemperature

[a] NO_x catalyst in system

Table 5-8. (Continued)

Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions gm/mi			Remarks
				AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
2823	Oldsmobile 455	5500	1/72		x	x			Base/Pellet (1259 JX3-1X1)	1975	10	0.34	10.7	2.1	
			1/72								3,336	0.41	10.3	2.0	
			2/72								8,927	0.62	11.6	2.0	Test continuing
18504	Oldsmobile 455	5500	3/72			x			Base/Pellet (1259 JX3-1X1)	1975	91	0.25	3.0	3.1	
			3/72								487	0.26	1.8	1.4	Test continuing
2233	Oldsmobile 455	4500	12/71		x	x			Base/Pellet (1259 JX3-1X1)	1975	0	0.31	5.6	2.1	
			1/72								14,227	0.48	10.7	1.6	
			1/72								19,868	0.52	11.7	1.6	
			2/72								24,304	0.56	8.6	1.9	
			3/72								30,037	0.73	10.6	2.3	Test discontinued
2590	Oldsmobile 455	5000	2/72		x	x			Base/Pellet (1259 JX3-1X1)	1975	47	0.42	7.0	2.3	
			3/72								1,418	0.61	7.9	3.5	Overtemperature
2539	Oldsmobile 455	5000	2/72		x	x			Base/Pellet (1259 JX3-1X1)	1975	1	0.30	4.6	2.3	
			3/72								1,139	1.04	11.0	2.4	Overtemperature
2878	Oldsmobile 455	5500	1/72						Base/Pellet (1259 JX3-1X1)	1975	8	0.22	-	3.8	
			2/72								2,460	0.51	7.5	5.6	Test continuing
2242	Buick 350	4500	3/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	0	0.56	5.9	1.8	
			3/72								3,950	0.74	5.7	1.5	Test continuing
62124	Buick 455	5000	2/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	43	0.38	4.1	5.6	
			2/72								2,910	1.08	7.2	5.3	
			3/72								7,280	0.43	3.6	4.9	
			3/72								10,097	0.98	9.9	5.9	Changing catalyst
62125	Buick 455	5000	2/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	32	0.64	3.6	5.7	
			2/72								3,201	0.72	4.0	5.7	
			3/72								7,198	1.16	7.1	5.8	
			3/72								10,469	1.24	9.6	5.7	Changing catalyst
62126	Buick 455	5000	2/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	33	0.54	2.1	6.0	
			2/72								3,381	0.65	3.3	5.5	
			3/72								7,096	0.67	3.8	4.9	
			3/72								10,079	0.71	3.2	5.1	Changing catalyst
62127	Buick 455	5000	2/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	17	0.56	3.9	5.7	
			2/72								3,342	0.91	9.3	5.1	
			3/72								7,111	0.93	9.5	5.1	
			3/72								10,006	0.99	10.1	6.5	Changing catalyst

Table 5-8. (Continued)

Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
				AIR	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
62129	Buick 455	5000	2/72 3/72 4/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	48 3,400 7,401	0.48 0.60 0.80	3.0 3.5 6.7	5.8 5.0 5.1	Test continuing
62128	Buick 455	5000	2/72 2/72 3/72 3/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	48 2,660 7,079 10,104	0.52 0.75 1.08 1.00	4.2 6.6 8.8 9.7	6.2 4.5 5.3 5.1	Changing catalyst
62130	Buick 455	5000	2/72 3/72 3/72	x		x			Base/Pellet (1259 JX3-1X1)	1975	39 3,405 7,362	0.53 0.65 0.86	4.1 5.9 7.6	4.4 4.8 3.7	Test continuing
62115	Buick 455	4900	1/72 3/72	x	x	x	x		Base/Pellet (1259 JX3-1X1)	1975	323 876	0.60 1.25	3.0 5.5	1.3 1.3	Changing catalyst
931	Buick 455	5000	12/71 1/72	x	x				Base/Pellet (1259 JX3-1X1)	1975	0 7,544	0.29 0.64	2.3 6.7	6.0 4.0	Test discontinued
2222	Cadillac 500	5500	1/72 1/72 2/72 4/72	x	x	x			Base/Pellet (1259 JX3-1X1)	1976	0 2,000 4,000 8,000	0.35 0.40 0.35 0.32	1.1 2.3 3.2 4.6	2.0 1.9 2.1 2.6	Test continuing

Table 5-10. Emissions Data From Chemico for Federal Clean Car Incentive Program

Test Date	Test Mileage Accumulated	Vehicle Tested	System Configuration	1st Bed Catalyst	2nd Bed Catalyst	1975 CVS-CH Test Procedure HC	1975 CVS-CH Test Procedure CO	1975 CVS-CH Test Procedure NO_x	Fuel Consumption, mi/gal	Remarks
3/7/72	1,495	(A)	Mach VIII	A	A	0.23	3.32	0.33	10.6	Meets 1976 standards
3/8/72	1,505	(A)	Mach VIII	A	A	0.15	1.36	0.26	11.0	Meets 1976 standards
3/9/72	1,517	(A)	Mach VIII	A	A	0.29	2.63	0.32	9.91	Meets 1976 standards
3/10/72	1,529	(A)	Mach VIII	A	A	0.19	2.29	0.31	9.95	Meets 1976 standards
3/16/72	1,588	(A)	Mach VIII	A	A	0.18	1.50	0.24	9.98	Meets 1976 standards
3/25/72	1,677	(A)	Mach VIII	A	A	0.19	1.12	0.29	12.9	Meets 1976 standards
3/27/72	1,790	(A)	Mach VIII	A	A	0.28	1.67	0.43	9.48	Meets 1976 standards
3/29/72	6,595	(B)	Standard production car	None	None	3.04	40.01	3.92	11.9	Meets 1972 standards
3/30/72	6,607	(B)	Standard production car	None	None	2.35	30.26	2.85	10.9	Meets 1972 standards
3/31/72	2,019	(A)	Mach VIII	A	A	0.38	2.18	0.30	9.97	Meets 1976 standards
4/6/72	2,556	(A)	Mach VIII	A	A	0.46	1.81	0.30	9.75	Distributor points burned
4/7/72	2,567	(A)	Mach VIII	A	A	0.63	2.06	0.36	10.40	Distributor points burned
4/11/72	2,784	(A)	Mach VIII	A	A	0.37	1.27	0.32	9.97	Points replaced Meets 1975 standards

Vehicle Tested: (A) 1971 Oldsmobile - Delta 88 - 350 cubic inch displacement - Test Inertia Weight: 4500 lb
(B) 1972 Oldsmobile - Delta 88 - 350 cubic inch displacement - Test Inertia Weight: 4500 lb (Avis Rental Car)

Tester/Location: Environmental Protection Agency - Ann Arbor, Michigan

In September 1971, CHEMICO's car was tested at GM Tech Center and again the emissions were below the 1976 emission levels.

In February 1972, CHEMICO's car was tested at Scott Research Laboratories, Plumsteadville, Pa. This car was submitted to EPA for evaluation under the Federal Clean Car Incentive Program. Early results from this EPA evaluation are presented in Table 5-10. All test data shown are for low mileage (less than 1500 miles) and with fresh catalyst. Considerable catalyst attrition was evident even below 1000 miles.

5.7.3.2 High Mileage Emissions

CHEMICO has no high mileage emission data.

5.7.4 Engelhard

Engelhard has been very active in performing tests to demonstrate the applicability of noble metal/monolith catalysts for automotive use.

5.7.4.1 Low and High Mileage Emissions

5.7.4.1.1 Durability on Dynamometer

As a baseline for durability of standard PTX-433, a test was run on an engine dynamometer using the mileage accumulation schedule shown in Figure 5-22 (Ref. 5-4). With this schedule inlet temperatures to PTX purifiers are approximately 900-1000°F. This particular catalyst was first tested on a car using lead sterile fuel. The car was involved in an accident at 4156 catalyst miles. One of the two purifiers on that V8 vehicle was damaged. The purifier which was intact was removed and installed on an engine dynamometer, and an additional 31,665 miles were accumulated with lead-free fuel and ashless lubricating oil. The results are shown in Figure 5-23.

After a total of 35,821 miles, the emissions were 0.35 gm/mi for hydrocarbons and 3.0 gm/mi for carbon monoxide.

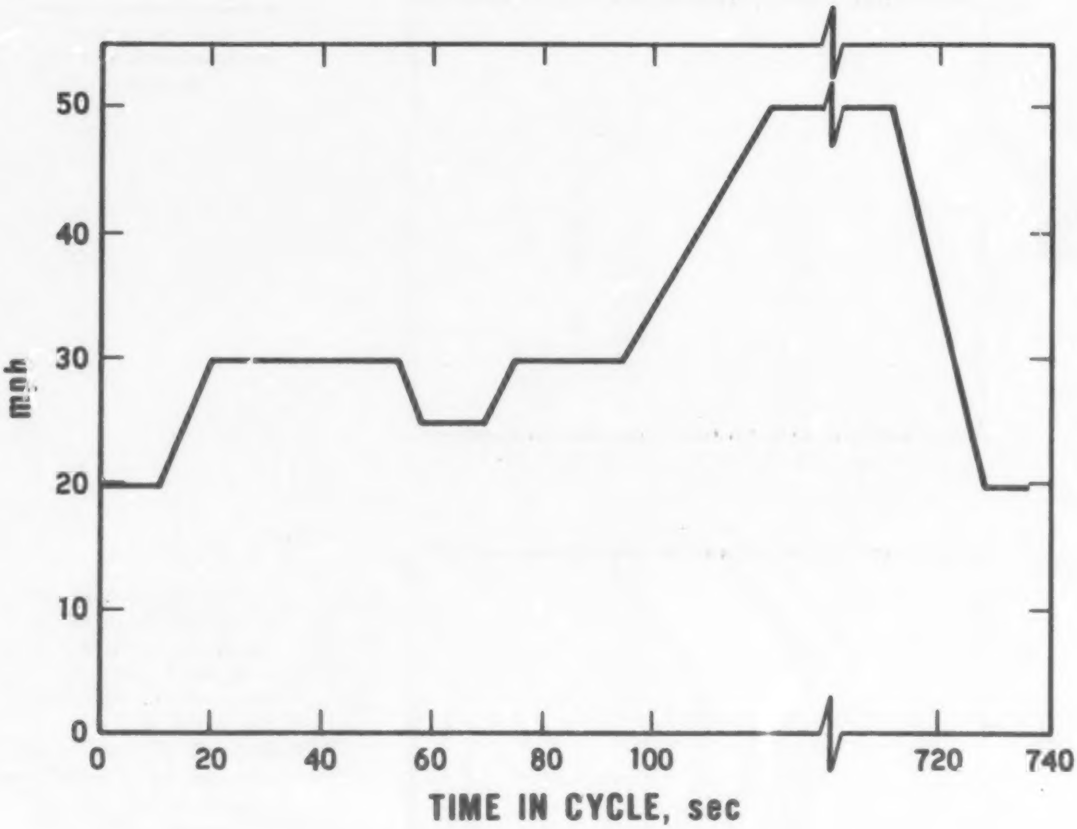
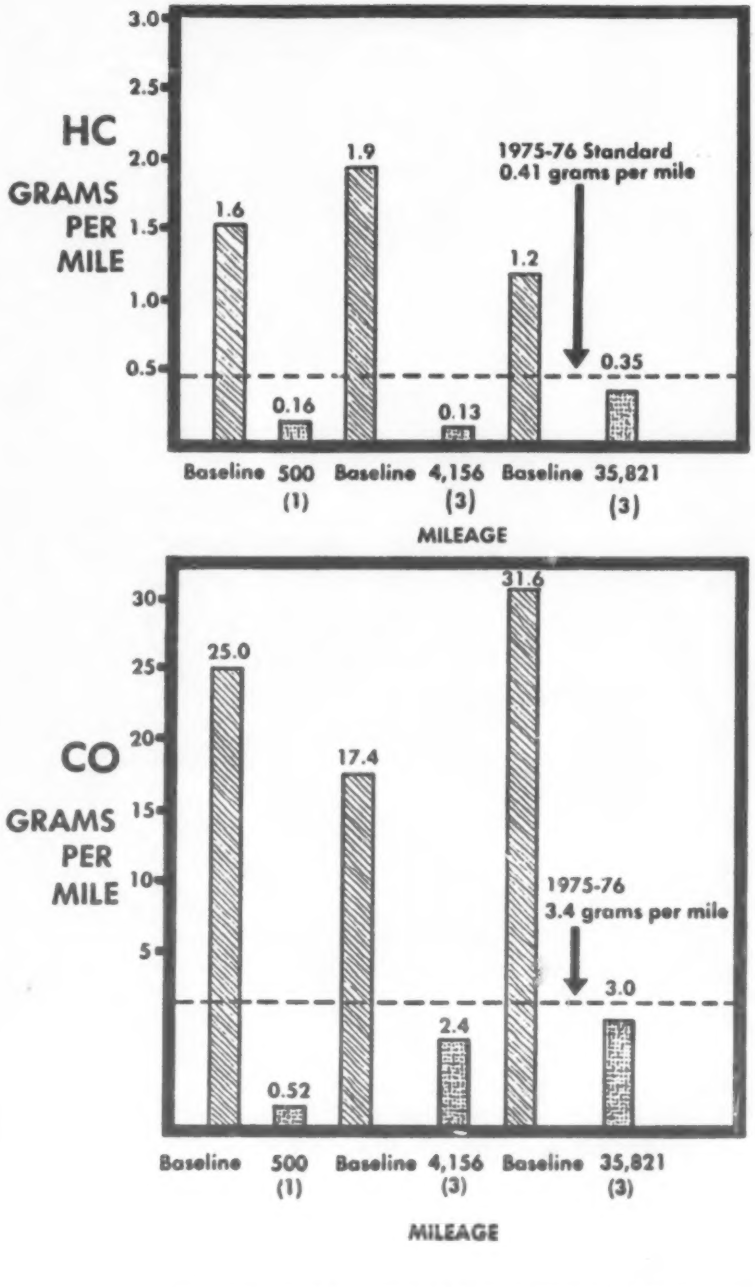


Figure 5-22. Englehard Mileage Accumulation Cycle for Engine Dynamometers



ON DYNAMOMETER

351 C.I.D. V8 Engine
Equipped with Air Pump,
No EGR

NOTES

1. Up to 4,156 miles accumulated on car (350 C.I.D. V8, air pump, A.I.R., no EGR) with lead sterile fuel and ashless lubricating oil, 500 miles test on this car.
2. 4,156-35,821 miles accumulated on engine dynamometer with lead free fuel and ashless lubricating oil.
3. CVS Test on car 351 C.I.D. V8, air pump, Thermactor, no EGR.
4. All data per 1975 CVS-CH Test Procedure.

Figure 5-23. Engelhard PTX-433 Catalyst Durability Test

5.7.4.1.2 Standard PTX Catalyst Durability Data

5.7.4.1.2.1 FTP Hot Cycle Emission Data

A 50,000-mile durability test was conducted (Ref. 5-25) for a standard PTX catalyst on a Ford Torino station wagon equipped with a 351 C.I.D. V8 engine, automatic transmission, no air pump, and no EGR. Each bank of the engine has a PTX-433S catalyst located about 18 inches downstream of the manifold under the front floor board. Commercially available lead-free fuel and standard lubricating oil were used. A city-suburban driving cycle was used for mileage accumulation with an average speed of 28 mph. This cycle consisted of driving on rural, city, and turnpike roads. The FTP hot cycle emission results for one of the PTX catalysts are shown in Figure 5-24. The catalyst maintained a high level of activity throughout the test period.

5.7.4.1.2.2 1975 CVS-CH Emission Data

To establish activity durability of the present PTX catalyst using 1975 CVS test procedures, a 25,000-mile test (Ref. 5-25) was conducted with a 1975 prototype exhaust emission control system which included an air pump, an exhaust gas recirculation (EGR) system, and two PTX-5 catalytic converters on a V-8 engine. A city-suburban driving cycle was used for mileage accumulation; Engelhard does not have a test track to allow strict compliance with the EPA Certification Test. Emission tests were conducted at approximately 4000-mile intervals. The data from this test are presented in Figure 5-25 in terms of HC and CO concentrations and catalyst system efficiencies. Catalyst deactivation during the 25,000-mile test was minimal for HC. The CO emissions increased by about 50 percent but were still below the 1975 standards.

5.7.4.1.3 Durability Test by Automotive Company

Engelhard has a close working relationship with substantially all of the domestic and foreign automotive companies. Figure 5-26 presents durability data reported by American Motors to Engelhard (Ref. 5-4). The test car

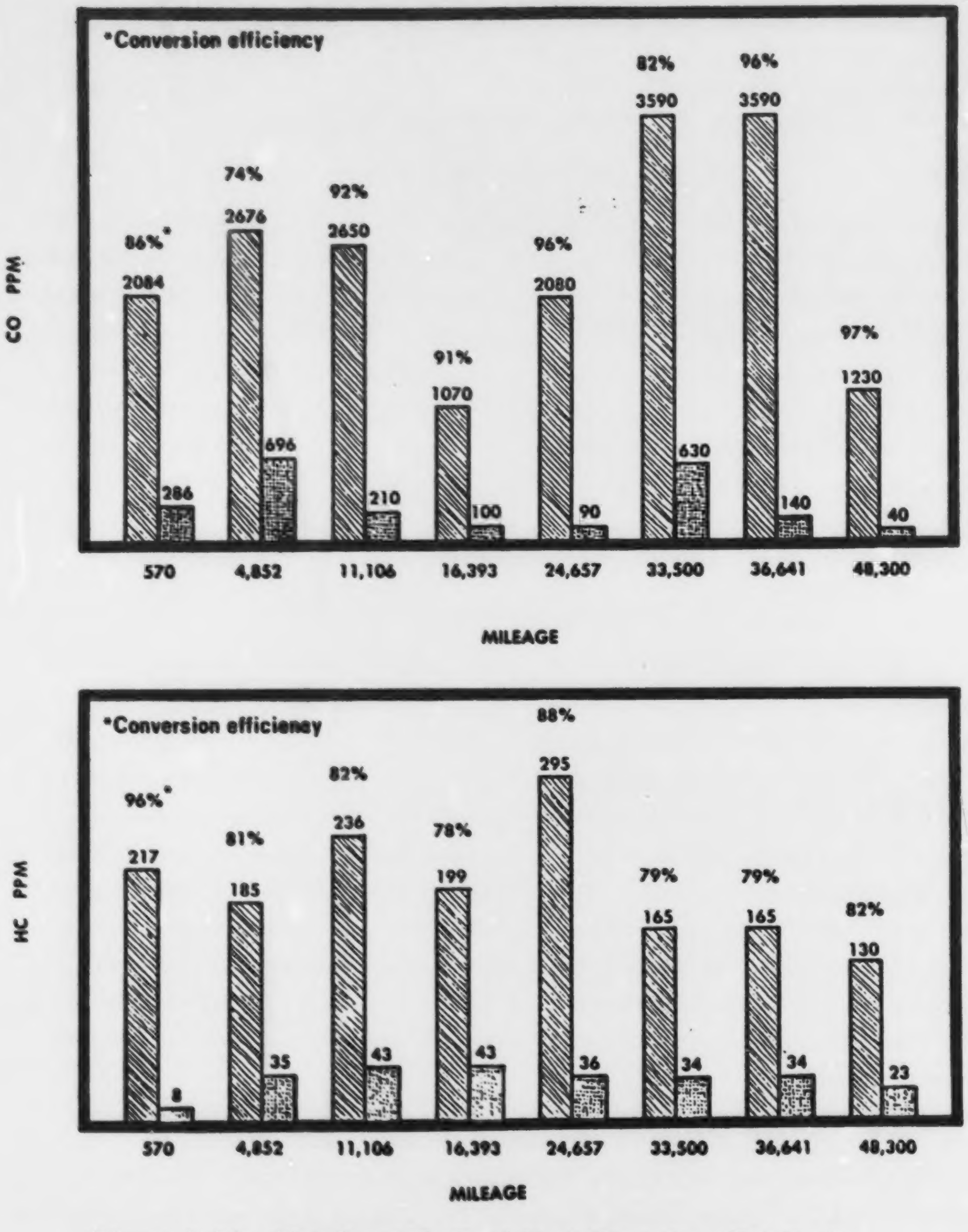
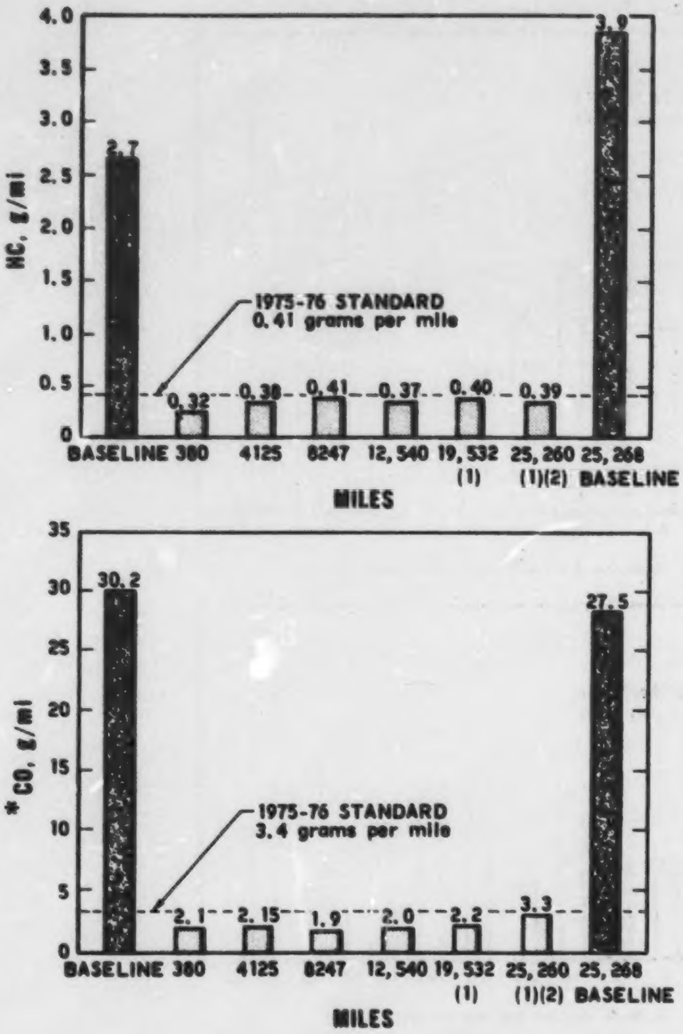


Figure 5-24. Engelhard Federal Test Procedure Hot Cycle Emission Data for a PTX-433-S Catalyst (Ford Torino - 351 CID Engine)



ON CAR - 351 C.I.D. V8 ENGINE

PTX-5 (8 corr. per in.)

CAR EQUIPPED WITH 1975 PROTOTYPE SYSTEM - EGR, AIR PUMP, PLATINUM CATALYST CONVERTER

NOTES:

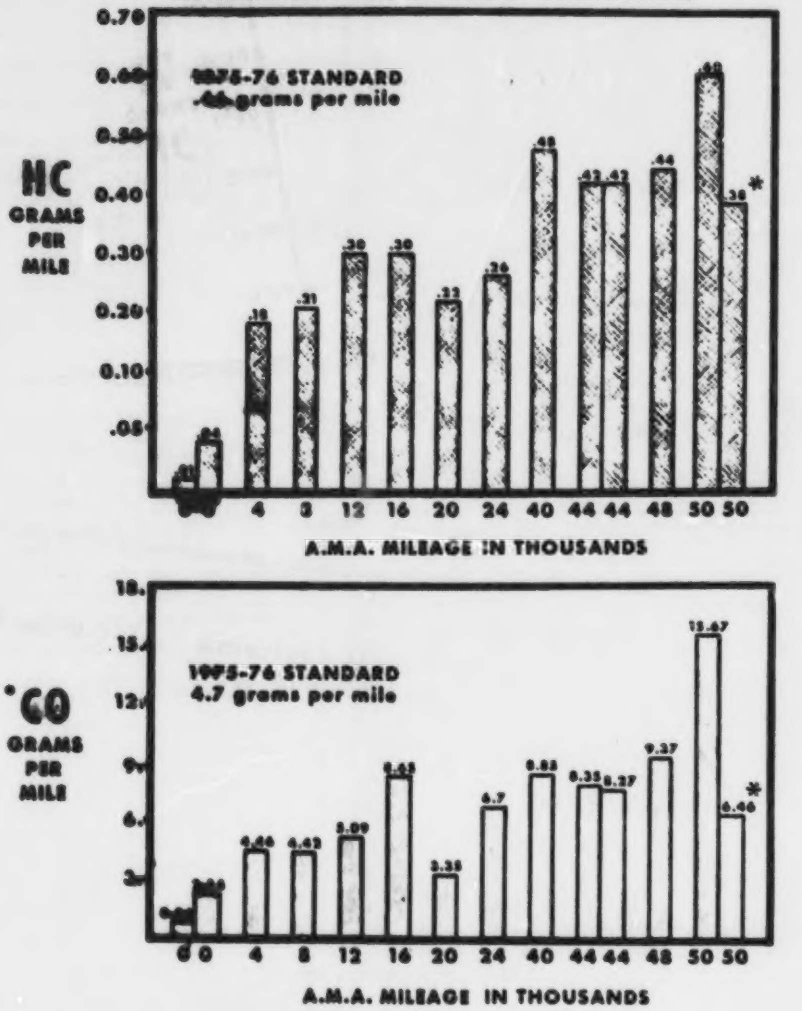
1. Manifold to catalyst insulated. Air pump output partially diverted after cold start.
2. Catalyst annulus insulated to prevent bypassing
3. No other adjustments to engine during test
4. Lead sterile fuel and ashless lubricating oil
5. 1975 CVS-CH test procedure used
6. City/suburban driving cycle

BASELINE - CAR WITHOUT CATALYST

* (NO_X level less than 3.0 grams per mile)

Figure 5-25. Englehard PTX-5 Catalyst Durability Test

6 CYLINDER CAR
(All tests except as indicated are '72 CVS-C test. '75 emission standards are stated in terms of '72 CVS-C tests.)



(NOx at 1.5-2.0 grams per mile)

• High CO due to slow choke-action - correctable by 1975 choke/carburetor-action *1975 CVS-CH

Figure 5-26. American Motors Durability Test of Englehard PTX-423-S Catalyst

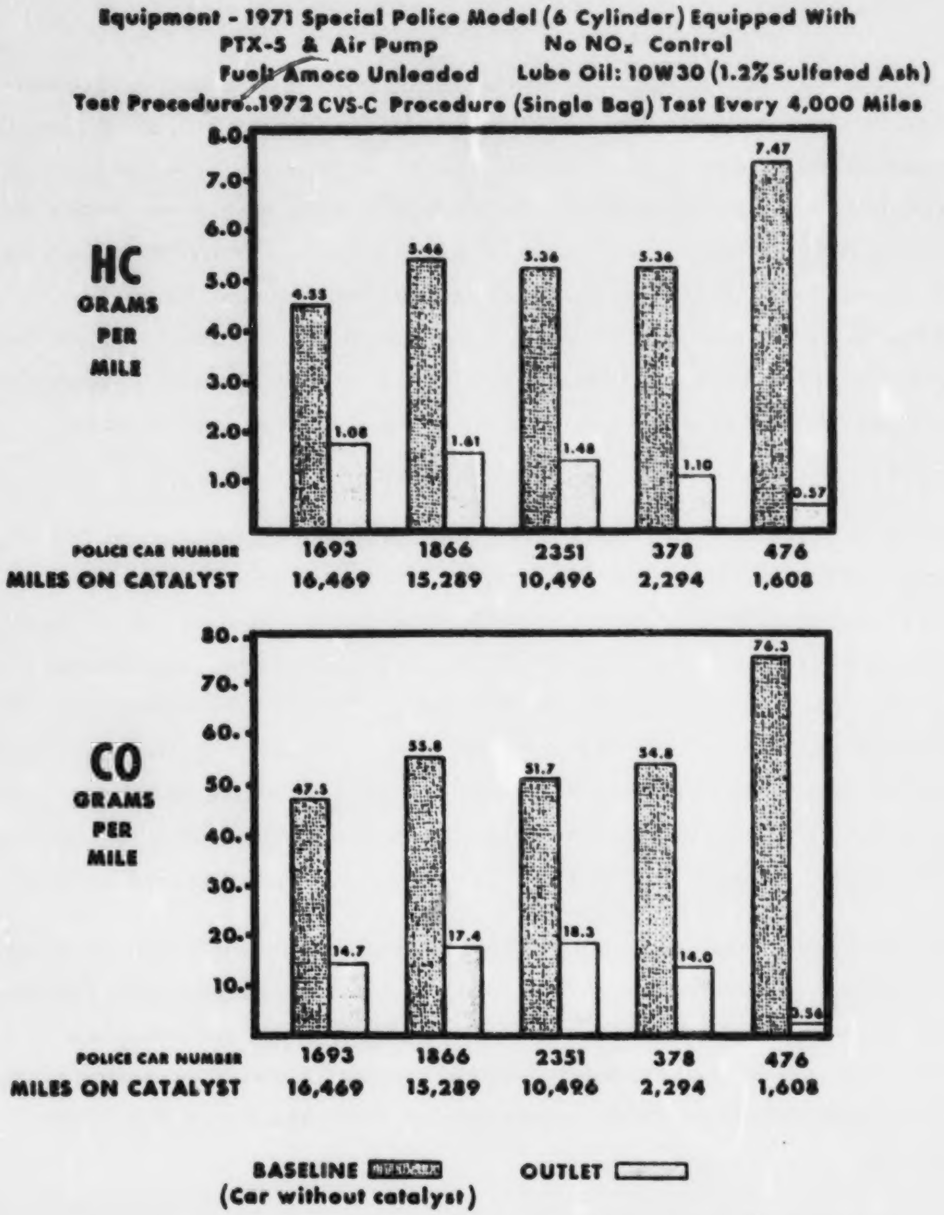
was new, but was not equipped with the improved chokes and carburetors projected for use in 1975 cars. The AMA driving cycle was used for mileage accumulation and, generally, emission tests were made at 4000-mile intervals using the 1972 CVS-C procedure. At 50,000-miles, a test was made using the 1975 CVS-CH procedure. As shown in Figure 5-26, the hydrocarbon emissions were 0.38 gm/mi and carbon monoxide emissions were 6.46 gm/mi. According to AMC, most of the carbon monoxide was emitted during the cold start portion of the test and that the projected 1975 choke and carburetor modifications might be expected to improve the system performance.

5.7.4.1.4 Retrofit Fleet Test of Durability

In addition to working with automotive manufacturers, Engelhard Industries has cooperated with fleet owners who are interested in retrofitting their cars or trucks with catalytic devices. One of these has involved the evaluation of PTX units by the city of New York on Police Department patrol cars (Ref. 5-4). The cars are 1971, six cylinder vehicles which has been using commercially available unleaded fuel prior to catalyst installation. However, since at some time the cars could have been inadvertently filled with leaded gasoline, the fuel and oil systems were drained and refilled with commercially available unleaded fuel and 10W30 engine oil (1.2 percent sulfated ash).

The cars are not designed to meet 1975 emission standards and have slowly acting chokes. In one instance, the choke did not fully open until 200 seconds after the start of the test. The retrofit consisted of an air pump and a PTX-5 catalyst. Mileage was accumulated in the normal service of police work, and there have been no unfavorable comments on driveability by the Police Department.

These tests are still in progress; the most recent data furnished by the city of New York using the 1972 CVS-C procedure are presented in Figure 5-27. As shown in this figure, the reduction of hydrocarbons and carbon monoxide emissions is significant.



Equipment - 1971 Special Police Model (6 Cylinder) Equipped With
PTX-5 & Air Pump No NO_x Control
Fuel: Amoco Unleaded Lube Oil: 10W30 (1.2% Sulfated Ash)
Test Procedure..1972 CVS-C Procedure (Single Bag) Test Every 4,000 Miles

Figure 5-27. Emission Data on New York City-Owned Police Cars Equipped with Engelhard PTX-5 Catalyst

According to Engelhard, the emission data for cars 1693, 1866, 2351, and 378 indicate a deficiency of required secondary air in some parts of the test cycle. Engelhard feels that a proper balance of raw emissions and secondary air would improve efficiency.

5.7.4.1.5 Activity for Removal of Reactive Hydrocarbons

Engelhard stresses (Ref. 5-25) that although the activity of a catalyst in use generally decreases with time, the PTX converter retains a high activity for the conversion of photochemically reactive hydrocarbons--olefins and aromatics--commonly recognized as being smog precursors. This is illustrated in Figure 5-28 which compares the activity (at steady state 30 MPH) of a PTX catalyst after 500 and 50,000 miles.

According to Engelhard, the significance of this finding is that there need be no stringent limits on olefin and aromatic content of lead free fuel when the PTX converter is used for automobile exhaust gas purification.

5.7.4.1.6 Improved PTX-Type Catalyst Durability Data

The data presented in Figures 5-23 through 5-28 were obtained with the standard PTX designed for automotive use. However, Engelhard (Ref. 5-4) feels that improvements can be made and expects to accomplish these prior to the 1975 model year. The improvement potential of Engelhard "second-generation" catalysts is indicated by its laboratory and engine dynamometer tests, but general durability confirmation has just started.

Figure 5-29 presents durability data for one of these improved catalysts which was tested with the air pump output partially diverted after cold start. Lead-sterile fuel and ashless lubricating oil were used. Prior to the 8550-mile test, the distributor points were replaced and the ignition readjusted.

Figure 5-29 shows that the hydrocarbon emissions for the improved PTX-5 at 8550 miles were 0.26 gm/mi as compared with the standard PTX-5 with 0.41 gm/mi at 8247 miles in Figure 5-25. The carbon monoxide emissions

	FRESH PTX (after 500 mi)	AGED PTX (after 50,000 mi)
SMOG PRECURSORS		
% REMOVAL OF HYDROCARBONS		
ACETYLENES	100.0	100.0
OLEFINS	99.1	93.7
AROMATICS	99.1	93.4
OTHER HYDROCARBONS		
OTHER PARAFFINS	93.9	36.8
METHANE	11.3	9.6
TOTAL HYDROCARBONS (carbon basis)	97.1	81.4
DECREASE IN TOTAL REACTIVITY OF EMITTED HYDROCARBONS	99.2	91.9

Figure 5-28. Engelhard Test Results (Steady State 30 MPH) - Removal of Olefins and Aromatics After 50,000 Miles

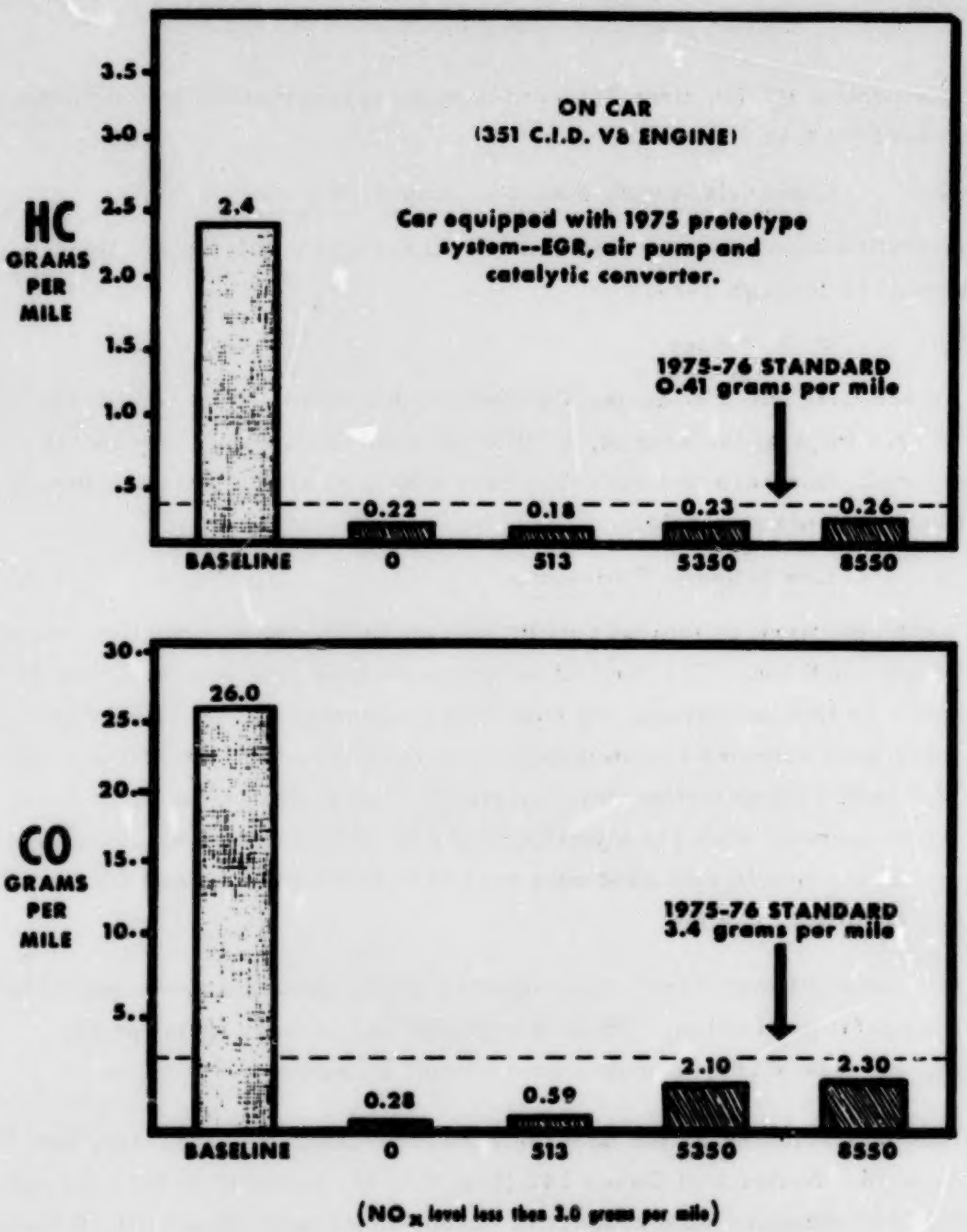


Figure 5-29. Engelhard Improved PTX-5 Catalyst Durability Test

for the improved PTX-5 after 8550 miles were approximately the same as the standard PTX at 8247 miles (See Figure 5-10).

5.7.4.2 Comparison with Auto Company Test Data

Representative auto company test data for Engelhard catalysts are presented in Tables 5-11 through 5-17.

5.7.5 W.R. Grace

W.R. Grace uses two 350-cu-in. Chevrolet automobiles in its test work: the first, a 1970 Impala; the second, a 1971 Chevelle (Ref. 5-5). These are regular production cars to which they have added an air pump which injects air into the exhaust manifold.

5.7.5.1 Low Mileage Emissions

Table 5-18 summarizes typical results obtained with Grace oxidation catalysts in the fresh condition. The circled values represent values at or below 1975 standards. In this tabulation, the catalysts designated as "D-" are materials which have been supplied to automobile manufacturers for test; those designated "R-" are still experimental materials. The emission levels of these cars, when operated with air injection in the manifold and no catalyst, are of the order of magnitude specified with regard to hydrocarbons and CO by the State of California for 1974.

As of the present time, Grace feels that two of its catalysts are candidates for commercial production. These are Davex 142, a base metal pellet catalyst, and Davex 502, a noble metal monolith catalyst.

Davex 502 was selected on the basis of data from Runs No. 221, 300, and 383 in Table 5-18. Notice that Davex 142 (Run No. 487 in Table 5-18) does not meet the 1975 standard with respect to carbon monoxide. However, it has been reported to Grace by the A-C Division of General Motors that tests with the Davex 142 catalysts have resulted in low mileage emission levels of 0.20-0.25 gm/mi of hydrocarbons and 2.0-2.5 gm/mi of carbon monoxide.

Table 5-11. Engelhard Catalyst Data--Chrysl

Test No.	Car No.	Model and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TP	Catalyst			HC	CO	NO_x	
1 21	119	440			x x	x				Noble/Mono 0.2% Pt; Oval 135 in.^{3}	1972 1975	0 1,268	0.51 0.23	3.0 1.9	3.5 1.28	No EGR EGR added; choke modification
1 6 30	134	GP57H43/360			x x	x				Noble/Mono 0.2% Pt; 5 in. o.d. 90 in.^{3}	1972 1972 1972	0 155 1,763	0.18 0.15 0.40	4.3 3.4 5.9	4.41 2.25 2.24	No EGR EGR above 120°F
2	145	318			x	x				Noble/Mono Oval (underseat)	1975	0	1.66	15.0	2.17	Very rich choke
1 35	258	GD57E41/360			x	x				Noble/Mono 0.35% Pt.	1972 1975	10 627	0.22 0.23	2.6 0.6	1.54 5.44	EGR off
1 30	278	GD57-41/360			x	x			30% Size	Noble/Mono	1972 1975	15 1,446	0.22 0.14	3.3 1.2	2.3 3.62	No EGR: double wall exhaust pipe added
1 27	303	GP57H43/360			x x	x			Cast Reactors	Noble/Mono 0.2% Pt; Oval	1972 1972	0 1,294	0.37 0.24	4.3 8.0	4.05 1.67	Double wall exhaust pi Baseline with EGR
7	306	GP57H43/360			x	x			Cast Reactors	Noble/Mono 0.2% Pt; Oval 135 in.^{3}	1972	1,030	0.12	5.7	.54	
24	326	HD63-M-41/400-2V			x	x	x			Noble/Mono 0.2% Pt; Oval	1975	1,201	0.48	2.3	2.4	
1 20 21	333	360			x	x				Noble/Mono 0.2% Pt; twin	1972 1972 1972	0 35,943 36,094	0.41 0.36 0.33	2.48 4.7 4.1	1.49 0.78 1.56	Replaced mono wrapp
1	376	HV24/225			x	x				Noble/Mono PTX 523	1975	0	0.35	4.5	2.24	
1 12	385	360-2V			x	x				Noble/Mono 0.35% Pt.	1972 1972	0 20,000	0.28 0.26	4.3 2.84	2.19 1.56	Catalyst failed

Table 5-11. (Continued)

Test No.	Car No.	Model and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
10	467	HP57P43/360			x	x			Cast Reactors	Noble/Mono 0.2% Pt; Oval	1975	171	0.12	6.5	1.43	
3	499	HP57/360			x	x			30% Cast Reactors	Noble/Mono 0.2% Pt; Oval	1975	107	0.2	3.3	2.19	
1 14	585	440			x	x				Noble/Mono 0.2% Pt; Oval	1975	0 13,678	0.73 0.44	2.3 2.1	2.41 1.50	
3 4 5 6	624	400								Noble/Mono 0.2% Pt; 5 in. o.d.	1972 Hot	0 381 1,104 1,434	0.10 0.37 0.20 0.12	5.9 3.2 2.8 4.6	3.12 4.49 4.26 3.66	Leaded fuel used Unleaded fuel used
1 3	650/698	400			x					Noble/Mono 0.2% Pt; Two 4 in. diam units	Hot 7-mode 1972 hot	0 43,000	0.12 0.16	1.51 1.88	- 3.91	Converters damaged
1 5	683	360			x	x				Noble/Mono 0.2% Pt; Oval	1972 1972	0 8,350	0.03 0.11	3.8 6.74	3.81 3.07	Double wall exhaust pi EGR above 120°F

Table 5-12. Engelhard Catalyst Data--Volvo, International Harvester, American Motors, and General Mot

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
520 776	OB 46232	'72 Model 142 E; Engine B20F		12/10/71 2/15/72	x					Noble/Mono PTX-416	1975	0 2,030	0.43 0.28	1.92 1.50	2.60 2.90	Volvo (Ref. 5-40, 5-46)
433	OB 46234	Model 144; Engine B20F		11/29/71	x					Noble/Mono PTX-416	1975	0 600	0.12 0.29	2.15 1.33	2.12 3.82	
913 1099	OB 54821	Model 144; Engine B20B		3/3/72 4/7/72	x					Noble/Mono PTX-416	1975	0 2,900	0.11 0.36	1.55 2.13	2.48 0.79	
601 1091	OB 46234 and OB 44085	'72 Model 144; Engine B20F		1/10/72 4/7/72	x	x				Noble/Mono PTX-416	1975	0 25,344	0.21 0.24	2.17 2.45	1.31 1.82	
	161	1100 D Travelall; V-345		1/20/72 2/26/72 3/26/72	x					Noble/Mono (Stacked Substrate)	1975	0 8,000 10,358	0.29 0.35	4.10 3.93	3.82 3.79	Int. Harvester (Ref. 5-47) Loose substrate
	D00-24	232-6	3000		x						1975	50,000	0.32[a]	4.80[a]	1.45	AM. Motors (Ref. 5-48)
	D00-25	232-6	3000		x						1975	24,000	0.75	8.57	2.75	
	61319	Chevrolet 350	4500	8/71 11/71 2/72	x	x	x			Noble/Mono PTX-4	1975	0 8,424 21,527	0.13 0.51 0.55	1.9 4.9 5.5	1.3 1.4 1.6	Gen. Motors (Ref. 5-45)
	1420	Opel 1.9 liter .	2500	2/72	x	x	x			Noble/Mono PTX	1975	0	0.23	2.7	1.5	
	17934	'71 Buick - 455		2/72	x					Noble/Mono PTX-423S (2) (0.2% Pt)	1975	70,000	0.85[b] 0.15	8.7[b] 1.8	3.5[b] 3.3	After completion of high speed tire test 70,000-mi run at Arizona track. Same car - Fresh PTX 423S catalysts

[a] Least squares straight line value [b] Average of two tests

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Table 5-13. Engelhard Catalyst Data--British Leyland

Car	Mileage	EGR	Emissions, gm/mi[a]		
			HC	CO	NO_x
Austin Marina (A)	0	No	0.11	1.78	1.86
	11,400[b]	No	0.28	2.73	2.32
	11,450	No	0.34	2.08	1.65
	17,000[b]	No	0.63	4.65	1.32
Austin Marina (A)	0	No	0.04	1.49	1.67
	4,000	No	0.098	0.92	2.27
Triumph GT-6 (C)	0	No	0.58	1.78	2.04
Triumph Spitfire (D)	0	No	0.50	1.95	1.87
TR-6 (E)	0	No	0.39	5.10	1.75
Jaguar XJ-6 (F)	0	Yes	0.08	2.80	0.86
	4,100	Yes	0.15	3.00	1.10

[a] 1975 CVS-CH test procedure

[b] Valve recession; new head fitted after test

Table 5-14. Engelhard Catalyst Data--Saab Scania

Test No.	Vehicle No.	Fuel System	Air Injection	EGR	Driving Cycle	Mileage	Emissions, gm/mi[a]		
							HC	CO	NO_x
1	340	El. Inj.	Yes	No	Normal	0	0.61	5.72	1.46
						4,550[b]	1.22	17.7	1.48
2	340	El. Inj.	Yes	No	Normal	0	0.33	4.32	1.12
						1,770[b]	0.95	16.51	1.34
3	271	Carb.	Yes	On - Off	MAR[c]	0	0.43	2.99	0.96
						7,700[b]	0.87	15.12	0.95

[a] 1975 CVS-CH test procedure

[b] Catalyst insert loose

[c] Mileage accumulation route (ave. speed = 32 mph, highest speed = 55 mph, 16 hr/day)

Table 5-15. Engelhard Catalyst Data--Daimler Benz

Test Date	Test No.	Car Model	License Plate	Emissions, gm/mi*			Oxidizer Catalyst	Vehicle Mass
				HC	CO	NO_x		
12-9-71	1778	220V25		0.38	3.48	0.61	Englehard	3500
12-10-71	1788	220V25		0.25	2.04	0.72	Engelhard	3500
12-16-71	1818	220V25		0.41	8.19	0.61	Engelhard	3500
1-31-72	2032	220VL5		0.23	2.84	0.44	Engelhard	3500
10-27-71	1579	250CE	114E73	0.75	5.43	1.16	Engelhard PTX-4.4.5	3500
10-29-71	1591	250	S-J8529	0.24	1.85	1.69	Engelhard 2 PTX-4, PTX-5	3500
11-3-71	1574	250CE	114E73	0.30	1.57	1.84	Engelhard PTX-4.4.5	3500
11-4-71	1611	250CE	114E73	0.36	1.74	1.97	Engelhard PTX-4.4.5	3500
11-11-71	1632	250CE	114E73	0.51	1.13	1.72	Engelhard PTX-4.4.5	3500
11-11-71	1636	250CE	114E73	0.22	1.85	1.94	Engelhard PTX-4.4.5	3500
11-12-71	1639	250CE	114E73	0.35	2.09	2.15	Engelhard PTX-4.4.5	3500
11-12-71	1640	250CE	114E73	0.27	2.69	1.27	Engelhard PTX-4.4.5	3500
11-15-71	1644	250CE	114E73	0.36	2.69	2.01	Engelhard PTX-4.4.5	3500
11-10-71	1655	250CE	114E73	0.51	3.69	1.65	Engelhard PTX-4.4.5	3500
11-10-71	1657	250CE	114E73	0.45	1.83	1.55	Engelhard PTX-4.4.5	3500
11-16-71	1679	250CE	S-J8191	0.73	1.73	1.82	Engelhard PTX-4.4.5	4000
11-18-71	1683	250CE	114E73	0.35	3.50	2.16	Engelhard PTX-4.4.5	4000
11-24-71	1710	250CE	114E73	0.56	4.39	2.12	Engelhard PTX-4.4.5	4000
12-8-71	1770	250CE	114E73	0.36	3.06	1.82	Engelhard PTX-4.4.5	3500
12-9-71	1780	250CE	114E73	0.34	3.52	2.20	Engelhard PTX-4	4000

Table 5-15. Engelhard Catalyst Data--Daimler Benz (Continued)

Test Date	Test No.	Car Model	License Plate	Emissions, gm/mi*			Oxidizer Catalyst	Vehicle Mass
				HC	CO	NO_x		
12-10-71	1791	250	S-J8529	0.30	3.04	1.89	Engelhard 2 PTX-4, PTX-5	3500
12-14-71	1805	250	S-J8191	0.33	3.18	1.36	Engelhard 2 PTX-4, PTX-5	3500
12-17-71	1827	250CE	114E73	0.33	3.16	1.88	Engelhard PTX-4	4000
1-24-72	1997	250CE	114E73	0.31	3.99	2.97	Engelhard PTX-4	4000
1-26-72	2015	280	S-J8191	0.68	7.21	2.24	Engelhard PTX-4	4000
3-6-72	2208	250CE	114E73	0.33	7.66	2.95	Engelhard PTX-4	4000
12-14-71	1807	W108	E60	0.47	3.99	1.60	Engelhard	4000
1-4-71	1873	W108		0.35	4.32	1.75	Engelhard	4000
1-7-72	1911	450	E60	0.20	3.37	2.05	Engelhard	4000
1-10-72	1912	450	E60	0.31	4.09	2.08	Engelhard	4000
1-27-72	2012	W108		0.40	3.62	2.34	Engelhard 4 PTX-4	4000
1-27-72	2020	W108		0.48	1.49	2.59	Engelhard 4 PTX-4	4000
2-2-72	2028	W108		0.11	3.42	1.91	Engelhard 4 PTX-4	4000
2-3-72	2057	W108		0.13	2.08	1.82	Engelhard	4000
2-8-72	2072	W108		0.17	2.41	1.70	Engelhard 4 PTX- 4	4000
2-9-72	2076	W108		0.22	2.81	1.61	Engelhard 4 PTX-4	4000
2-10-72	2079	W108		0.16	1.88	1.57	Engelhard	4000
2-11-72	2084	W108		0.19	1.90	1.23	Engelhard 4 PTX-4	4000
2-16-72	2085	W108		0.12	2.35	1.19	Engelhard 4 PTX-4	4000
2-15-72	2099	W108		0.14	2.87	1.18	Engelhard 4 PTX-4	4000

Table 5-15. Engelhard Catalyst Data--Daimler Benz (Continued)

Test Date	Test No.	Car Model	License Plate	Emissions, gm/mi*			Oxidizer Catalyst	Vehicle Mass
				HC	CO	NO_x		
2-18-72	2110	W108		0.13	2.45	1.35	Engelhard 4 PTX-4	4000
2-25-72	2151	W108	E60	0.22	3.81	1.17	Engelhard	4000
3-3-72	2197	W108		0.13	5.56	0.97	Engelhard 4 PTX-4	4000
3-7-72	2204	W108		0.10	3.17	1.44	Engelhard PTX-4	4000

*1975 CVS-CH test procedure

Table 5-16a. Engelhard Catalyst Data – Ford Riverside Program (Group I Single Catalyst) (Ref. 5-35)

Vehicles		0 Miles			2000 Miles			4000 Miles			0-4000 Mile Deterioration Factor		
		HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
250 Maverick (1) PTX-6. 35	-1	0. 41	2. 23	2. 45	0. 58	3. 28	2. 96	0. 63	3. 56	3. 48	1. 5	1. 68	1. 52
250 Maverick	-2	0. 32	0. 95	2. 92	0. 35	1. 37	4. 2	0. 42	3. 19	3. 04	1. 34	3. 53	1. 03
351 Ford (2) PTX-5. 35	-1	0. 19	1. 91	2. 34	0. 43	3. 17	2. 47	0. 25	1. 91	2. 56	1. 49	0. 9	1. 09
351 Ford	-2	0. 2	1. 75	2. 46	0. 22	2. 32	2. 75	0. 32	2. 29	2. 89	1. 65	1. 29	1. 17
360 F-100 (1) PTX-7. 35	-1	0. 55	4. 42	2. 30	0. 47	3. 82	2. 55	0. 38	4. 4	2. 47	0. 69	0. 93	1. 07
360 F-100	-2	0. 49	2. 83	2. 45	0. 36	2. 41	2. 81	0. 33	2. 11	2. 74	0. 65	0. 74	1. 12
460 Lincoln (2) PTX-6. 35	-1	0. 63	3. 21	2. 36	0. 54	3. 52	2. 25	0. 6	3. 21	2. 35	0. 96	1. 0	0. 95
460 Lincoln	-2	0. 43	2. 88	2. 16	0. 54	3. 39	2. 31	0. 7	4. 43	2. 51	1. 13	1. 55	1. 14
Average:		0. 40	2. 52	2. 43	0. 44	2. 91	2. 79	0. 45	3. 14	2. 76	1. 18	1. 45	1. 14

Note: Emission values (in grams per mile) are the average of two consecutive 1975 CVS-CH Tests.

Table 5-16b. Engelhard Catalyst Data – Ford Riverside Program (Group II, Extra Catalyst with Reactor) (Ref. 5-35)

Vehicles	0 Miles			2000 Miles			4000 Miles			0-4000 Mile Deterioration Factor		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
250 Maverick -1 (2) PTX-6.35	0.22	3.23	1.76	0.32	2.98	2.02						
250 Maverick -2	0.54	8.74	1.68	0.49	9.79	1.83						
351 Ford -1 (2) PTX-5.35 (1) PTX-7.35	0.36	3.72	2.17	0.27	2.93	2.06	0.40	4.82	2.08			
351 Ford -2	0.32	4.21	1.76	0.4	4.65	1.88	0.32	5.58	1.57			
360 F-100 -1 (2) PTX-7.35	0.38	4.45	1.44	0.39	4.99	1.62	0.4	5.63	1.75	1.07	1.03	1.23
360 F-100 -2	0.24	3.96	3.12	0.25	3.43	2.55	0.26	3.16	1.91			
460 Lincoln -1 (2) PTX-6.35 (1) PTX-7.35	0.23	2.22	2.33	0.27	4.29	2.63	0.26	3.58	2.33	1.13	1.51	1.0
460 Lincoln -2	0.32	4.51	1.97	0.35	6.28	2.02	0.37	5.6	2.17	1.17	1.22	1.11
Average:	0.33	4.38	2.03	0.34	4.92	2.08	0.34	4.62	2.09	1.12	1.25	1.11

Note: Emission values (in grams per mile) are the average of two consecutive 1975 CVS-CH tests.

Table 5-16c. Engelhard Catalyst Data – Ford Riverside Program (Group III, Extra Catalyst) (Ref. 5-35)

Vehicles	0 Miles			2000 Miles			4000 Miles			0-4000 Miles Deterioration Factor		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
250 Maverick -1 (2) PTX - 6.35	0.32	0.6	2.34	0.31	1.11	3.09	0.37	0.95	3.36	1.02	1.71	1.59
250 Maverick -2	0.21	1.73	2.08	0.6	2.18	2.7						
351 Ford -1 (2) PTX - 5.35 (1) PTX - 7.35	0.17	1.77	2.26	0.2	1.51	2.2	0.28	1.56	2.45			
351 Ford -2	0.26	1.53	2.19	0.34	1.46	2.26						
360 F-100 -1 (2) PTX - 7.35	0.34	4.71	2.05	0.40	4.01	1.98						
360 F-100 -2	0.32	1.71	2.09	0.24	1.08	2.24						
460 Lincoln -1 (2) PTX - 6.35 (1) PTX - 7.35	0.28	1.59	2.1	0.31	3.35	2.59						
460 Lincoln -2	0.24	4.26	2.18	0.31	5.68	1.99						
Average:	0.27	2.24	2.16	0.36	2.59	2.35						

Note: Emission values (in grams per mile) are the average of the consecutive 1975 CVS-CH tests.

Table 5-16d. Engelhard Catalyst Data — Ford Riverside Program (Group I, Single Catalyst)

Vehicle	HC	CO	NO_x	HC	CO	NO_x
		4000 Mile			8000 Mile	
250 Maverick C-1	0.66	3.36	3.77	0.78	2.28	3.37
(1) PTX - 6.35	0.59	3.76	3.19	0.66	2.37	3.46
		2000 Mile			4000 Mile	
250 Maverick C-2	0.33	1.12	3.70	0.41	3.60	3.05
(1) PTX - 6.35	0.36	1.61	4.69	0.42	2.67	3.02
		4000 Mile			8000 Mile	
351 Ford C-1	0.20	1.69	2.52	0.25	1.84	2.55
(2) PTX - 5.35	0.30	2.12	2.60	0.23	2.32	2.45
		4000 Mile			8000 Mile	
351 Ford C-2	0.37	2.44	2.77	0.24	2.45	2.45
(2) PTX - 5.35	0.26	2.13	3.00	—	—	—
		2000 Mile			4000 Mile	
360 F-100 C-1	0.62	4.37	2.86	0.41	4.21	2.47
(1) PTX - 7.35	0.32	3.26	2.24	0.34	4.59	2.46
		2000 Mile			4000 Mile	
360 F-100 C-2	0.34	2.10	2.76	0.32	2.12	2.72
(1) PTX - 7.35	0.38	2.72	2.85	0.33	2.09	2.76
		2000 Mile			4000 Mile	
460 Lincoln C-1	0.47	3.22	2.27	0.57	2.93	2.26
(2) PTX - 6.35	0.61	3.82	2.23	0.63	3.49	2.44
		4000 Mile			8000 Mile	
460 Lincoln C-2	0.94	4.46	2.61	0.57	3.63	2.40
(2) PTX - 6.35	0.46	4.39	2.41	—	—	—

Note: Emission values (in grams per mile) are the average of two consecutive 1975 CVS-CH tests

Table 5-17. Engelhard Catalyst Data-Ford "1975 Durability Test Program" (Ref. 5-35)

Engine/Vehicle Combination	System Description					AMA Durability Mileage	Cold Emissions,[1] gm/mi			Hot Emissions, gm/mi			Remarks
	AI	EGR	Mod. Carb.	TR	Catalyst		HC	CO	NO$_x$	HC	CO	NO$_x$	
12A90-D 1971 400 2V A/T Ford	x	x	x	Type H	PTX 5.35 (2)	0 30,000	0.41 1.56	4.68 31.78	0.70 1.63	0.28 0.84	1.39 17.0	0.81 0.95	Right converter failed
1P38-D 1971 2.0L-2V A/T Pinto	x	x	x	Phase I; No core	PTX 5.35 (1)	1,500 16,500	- 0.17	- 6.86	- 1.52	0.07 0.11	0.23 7.25	1.29 1.09	
1A58-D 1971 351W-2V A/T Ford	x	x	x	Type H	PTX 5.35 (R-Side) PTX 5.10 (L-Side)	0 25,000 25,000	0.23 3.10 1.24	3.11 12.13 11.48	1.27 1.42 1.62	0.10 3.08 0.67	1.41 9.43 5.66	0.99 0.35 0.95	Three port liners failed After valve job
17A56-D 1971 351W A/T Ford	x	x	x	Type H	PTX 5.35 (R-Side) PTX 5.2 (L-Side)	0 45,000	0.29 0.83	8.36 15.09	0.86 1.43	0.17 0.81	2.61 6.98	0.83 0.63	
1L27-D 1971 460V A/T Lincoln	x	x	x	Phase I No core	PTX 6.35 (2)	0 35,000	0.25 0.53	3.82 3.66	0.88 1.59	0.05 0.46	2.70 3.61	0.68 1.52	Reworked left reactor; new head liners

[1] 1972-CVS-C test procedure

Table 5-18. Grace Vehicle Emission Data (1975 CVS-CH Test Procedure)

Run No.	Catalyst Designation	Vehicle	Catalyst Type	Catalyst Volume, in^3	Emissions, gm/mi	
					HC	CO
88	D45	–	Pellet, Base	300	0.30	5.90
18	D-45V	–	Pellet, Base	300	0.28	4.70
270	D-115	1970	Pellet, Base	300	0.24	5.37
93	D-117	–	Pellet, Base	300	0.29	6.41
239	D-135	1970	Pellet, Base	300	0.27	3.99
245	D-138	1971	Pellet, Base	300	0.22	4.94
275	R-9119	1970	Pellet, Base	300	0.17	3.24
280	D-139	1970	Pellet, Mix	300	0.11	2.21
487	D-142	1971	Pellet, Base	300	0.15	3.87
250	D-501	1971	Monolith, Base	70	0.30	3.77
286	R-9109	1971	Monolith, Mix	70	0.31	2.32
221	D-502	1970	Monolith, Noble	51	0.18	2.65
300	D-502	1971	Monolith, Noble	51	0.21	1.70
383	D-502	1971	Monolith, Noble	36	0.27	2.27
414	D-602	1971	Monolith, Noble	36	0.31	2.72

Note:

Pellet	Nominal 1/8-in dia ball or extrudate
Monolith	Ceramic (Cordierite) structure
Base	Base metal catalytic agent
Noble	Main catalytic agent of noble metal
Mix	Main catalytic agent of base metal – promoted by more than trace quantity of noble metal
⬭	Values at or below 1975 emission standards

5.7.5.2 High Mileage Emissions

The only data received by Grace from automobile companies are results reported by GM on two catalysts. One of these, [illegible]vex 45V, was aged for 50,000 miles by the AMA durability procedure and the emission levels determined by the 1972 CVS-C procedure. The other catalyst, Davex 42, was aged for 50,000 miles; however, no emission data were provided by Grace. A standard 1970 vehicle with a 350 cubic inch engine was used in these tests.

Figures 5-30 and 5-31 show the GM results translated to 1975 CVS-CH values using a correlation developed by Grace for pellet catalysts (Ref. 5-5).

The 50,000 mile, 1975 CVS procedure levels for this catalyst are 0.6 gm/mi hydrocarbons and 11 gm/mi carbon monoxide. Grace stated that it had specified a temperature limit of 1600°F for this catalyst, but the catalyst was exposed to temperature excursions as high as 2000°F and operated a substantial portion of the time above 1600°F during the first 3000 miles. By the end of the test the catalyst had undergone substantial shrinkage (but no weight loss) and there was possible bypassing or channeling in the container. To the best of Grace's knowledge, the 1970 vehicle used in this test was not specially provided with low emission hardware other than air injection into the exhaust manifold.

5.7.5.3 Comparison with Auto Company Test Data

Applicable auto company data from Chrysler (Ref. 5-17), International Harvester (Ref. 5-47), and General Motors (Ref. 5-45) are shown in Table 5-19. The maximum mileage reported is 23,000 miles.

5.7.6 Johnson-Matthey

Johnson-Matthey, the parent company of Matthey Bishop, has reported (Ref. 5-13) results from a vehicle configured to demonstrate its catalytic converter concept (noble metal/monolith). The test vehicle is a Chrysler Avenger with a 1.5 liter GL Plymouth Cricket engine designed to meet 1972

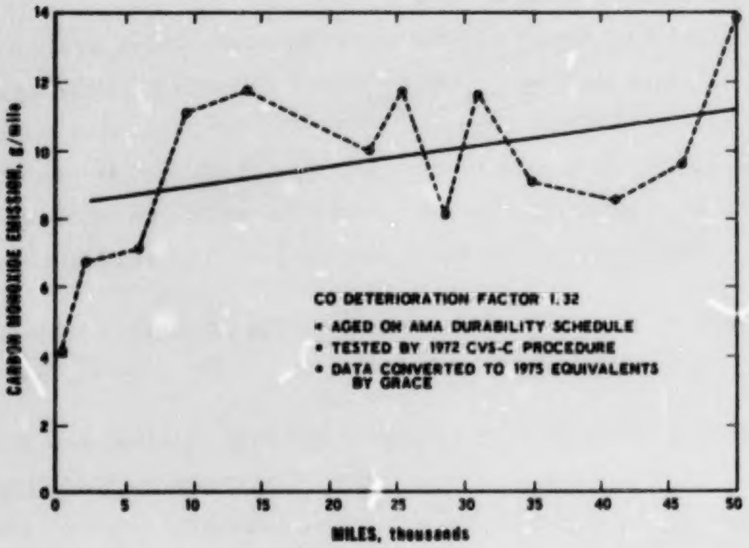

Figure 5-30. General Motors Durability Evaluation of Davex 45-V Catalyst (CO Emissions)

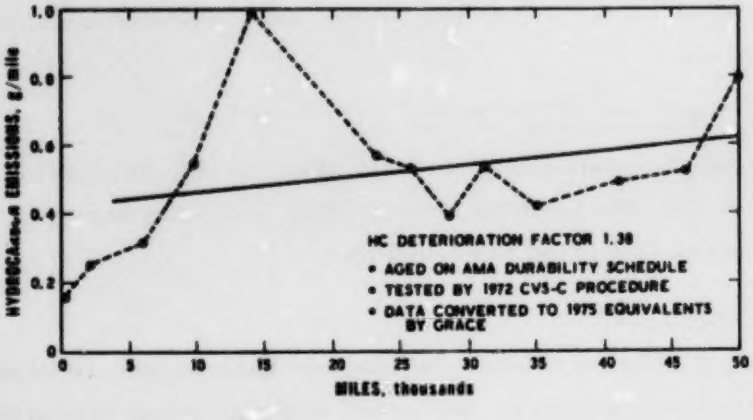

Figure 5-31. General Motors Durability Evaluation of Davex 45-V Catalyst (HC Emissions)

Table 5-19. W.R. Grace Catalyst Data

5-105

					System Description								Emissions, gm/mi			
Test No.	Car No.	Car and/or CID	Test Weight	Test Date	AI	EGR	Mod. Carb.	EFE	TR	Catalyst	Test Proc.	Test Mileage	HC	CO	NO_x	Remarks
	Chrysler															
2	117	360			x	x			30% Size	Noble/Mono Davex 47V 3 x 3-1/4 in. Discs (2)	1972	0 459	0.40 0.60	8.3 5.1	1.01 1.41	
36	258	GD57E41/360			x					Base/Pellet Davex 45V	1975	0	0.66	4.1	5.93	
	Int. Harvester															
	161	1100D Travelall; V-345			x					Noble/Mono (Spiral Substrate)	1975	0 16,000	0.46 0.46	5.1 6.85	4.51 3.99	
	General Motors															
	61336	Chev 350	4500	7/71	x	x	x			Base/Pellets (Davex 117)	1975	800	0.30	7.0	1.3	(Arvin co-op)
	61341	Chev 350	4500	8/71	x	x	x			Base/Pellets (Davex 117)	1975	400	0.50	7.0	1.1	(Norris co-op)
	61340	Chev 350	4500	8/71	x	x	x			Base/Pellets (Davex 117)	1975	150	0.60	10.0	1.4	(Walker co-op)
	61339	Chev 402	4900	10/71	x	x	x			Base/Pellets (Davex 117)	1975	100	0.37	12.8	0.8	
	61324	Chev 402	4500	6/71	x	x	x			Base/Pellets (Davex 117)	1975	1,000	0.36	4.1	0.9	
	2827	Buick 455	5000	2/72	x	x				Base/Pellets Davex 142 SMR 7-3881	1975	88	0.27	4.2	3.7	
	2823	Buick 455	5008	1/72	x	x				Base/Pellets Davex 142 SMR 7-3881	1975	0	0.20	4.7	2.9	
	1246	Cad 500	5500	1/72	x	x	x			Base/Pellets Davex 117	1975	0	0.27	1.7	2.9	
	2014	Olds 350	4500	2/72 3/72 4/72		x	x			Base/Pellet Davex 142 SMR-7-3881	1975	20 3,034 6,436	0.59 0.70 0.89	11.1 11.6 15.5	2.1 2.0 2.9	
	2611	Olds 350	5000	2/72 3/72 4/72		x	x	x		Base/Pellet Davex 142 SMR-7-3881	1975	0 6,337 12,022	0.40 0.52 0.91	9.0 17.7 24.0	2.3 2.4 2.2	
	2484	Olds 455	5000	2/72 3/72						Base/Pellet Davex 142 SMR-7-3881	1975	2 1,000	0.33 0.34	6.5 6.4	3.9 3.2	
	1450	Opel 1.9 Liter	1500	12/71 1/72 2/72	x	x	x			Base/Pellet Davex 117		0 12,000 23,000	0.53 0.73 1.2	10.4 10.8 22.9	1.7 2.2 2.5	

emission regulations, equipped with Stromberg CD2SE low emission carburetor and vacuum advance-retard distributor. It is modified to a low compression engine (8:1) with improved valve seats for use with lead-free fuel. The modifications include an EGR system, and a manifold air oxidation system designed by Ricardo & Company Engineers, Limited, equipped with a Lucas AP1F air pump (4 ft^3/min at 850 rpm running at 1:1 engine speed) and a Smith air dump valve for deceleration modes.

An AEC3A catalyst is used in the current test program. It has ceramic monolith supports for low pressure drop, high thermal and mechanical shock resistance, low attrition loss, and low thermal mass. The support is treated with a proprietary wash coat to increase the area available for deposition of the active catalyst. The catalyst formulation is based on promoted platinum metals for increased effectiveness.

Johnson-Matthey reports that with these engine modifications vehicle driveability is not significantly impaired; however, performance of the vehicle decrease marginally due to the use of EGR and the pressure drop in the catalyst unit. The fuel penalty incurred is not expected to be more than 5 percent, and possibly less than 3 percent. The gasoline used for the endurance test has a reported lead content of 0.000563 gm/gal.

The vehicle has been tested according to the 1975 CVS-CH test procedure. The breakdown of CVS tests is quoted for reference, giving the total emissions (in grams) for the three exhaust bags: cold transient (first 505 seconds), cold stabilized (rest of driving cycle), and hot transient (second 505 seconds). Johnson-Matthey intends to continue this road test until 50,000 miles have been completed or until the level of emissions exceeds 1975 standards.

5.7.6.1 Durability Test Results

The emissions over the 1975 CVS-CH Test procedure for the first 24,000 miles of the durability run are presented in Table 5-20. A complete breakdown of emissions for the three bags is presented in Table 5-21. The CO and NO

Table 5-20. Johnson-Matthey Avenger Durability Results
(Catalyst EC 3A/4 — E/BA25/90

Miles	HC[1]	CO[1]	NO_x[1]
0	0.11	0.85	1.65
500	0.09	0.58	1.93
1,000	0.106	1.03	2.16
2,000	0.16	0.75	2.07
3,000	0.15	0.88	1.84
4,000	0.15	0.91	1.81
6,000	0.19	0.91	2.10
8,000	0.17	0.73	2.09
10,000	0.19	0.51	2.03
12,000, preservice	0.21	0.74	1.77
12,000, post-service	0.21	0.71	1.50
16,000	0.30	0.74	2.04
20,000	0.26	1.06	1.76
24,000, preservice	0.33	1.33	2.01

[1] 1975-CVS-CH test procedure; emissions in gm/mi.

Table 5-21. Johnson-Matthey Avenger Durability Complete Bag Results for Catalyst EC 3A/4 – E/BA25/90

Miles	Emissions				
		HC	CO	NO_x	
0	CT	1.40	11.70	6.60	gm
	CS	0.15	1.01	4.96	gm
	HT	0.19	0.61	8.08	gm
	SW	0.11	0.85	1.65	gm/mi
500	CT	0.81	7.01	8.38	gm
	CS	0.19	1.00	5.77	gm
	HT	0.24	0.59	8.93	gm
	SW	0.09	0.581	1.93	gm/mi
1,000	CT	1.06	11.73	8.98	gm
	CS	0.19	2.02	6.28	gm
	HT	0.25	1.18	10.65	gm
	SW	0.106	1.03	2.16	gm/mi
2,000	CT	1.36	10.00	9.7	gm
	CS	0.37	1.01	6.1	gm
	HT	0.4	0.6	9.2	gm
	SW	0.16	0.75	2.7	gm/mi
3,000	CT	1.40	11.54	7.49	gm
	CS	0.29	0.99	5.72	gm
	HT	0.42	1.17	8.53	gm
	SW	0.15	0.88	1.84	gm
4,000	CT	1.47	12.05	8.7	gm
	CS	0.25	0.99	5.5	gm
	HT	0.38	1.16	7.66	gm
	SW	0.15	0.91	1.81	gm/mi
6,000	CT	1.78	12.77	8.95	gm
	CS	0.41	1.00	6.53	gm
	HT	0.44	0.59	9.43	gm
	SW	0.19	0.91	2.10	gm/mi
8,000	CT	1.25	8.8	9.15	gm
	CS	0.43	1.01	6.49	gm
	HT	0.61	1.19	9.22	gm
	SW	0.17	0.73	2.09	gm/mi

Table 5-21. Johnson-Matthey Avenger Durability Complete Bag Results for Catalyst EC 3A/4 – E/BA25/90 (Continued)

		Emissions			
Miles		HC	CO	NO_x	
10,000	CT	1.06	4.83	9.01	gm
	CS	0.55	1.04	6.45	gm
	HT	0.80	1.22	8.67	gm
	SW	0.19	0.51	2.04	gm/mi
12,000, preservice	CT	1.72	8.86	7.92	gm
	CS	0.46	1.02	6.21	gm
	HT	0.73	1.2	6.48	gm
	SW	0.21	0.74	1.77	gm/mi
12,000, post-service	CT	1.66	8.37	8.83	gm
	CS	0.46	1.03	6.08	gm
	HT	0.74	1.21	8.93	gm
	SW	0.21	0.71	1.49	gm/mi
16,000	CT	1.79	8.22	9.03	gm
	CS	0.90	1.01	6.38	gm
	HT	1.03	1.77	8.91	gm
	SW	0.30	0.74	2.04	gm/mi
20,000	CT	1.89	13.91	7.10	gm
	CS	0.66	0.99	5.55	gm
	HT	0.88	1.75	8.14	gm
	SW	0.26	1.06	1.76	gm/mi
24,000, preservice	CT	2.52	18.43	8.28	gm
	CS	0.85	1.02	6.33	gm
	HT	0.95	1.80	9.13	gm
	SW	0.33	1.33	2.01	gm/mi

CT	Cold transient
CS	Cold stabilized
HT	Hot transient
SW	Sum weighted

emissions are relatively constant over the test run whereas HC emissions are rising. The cause of increased HC emission is currently under investigation. These data trends are shown graphically in Section 3. 1. 7.

5. 7. 6. 2 Comparison with Auto Company Test Data

Applicable auto company test data for Johnson-Matthey catalysts are shown in Table 5-22 for British Leyland (Ref. 5-23), Volvo (Ref. 5-46), Daimler-Benz (Ref. 5-49), and Saab-Scania (Ref. 5-33). The maximum mileage reported is 2520 miles (Saab).

5. 7. 7 Monsanto

Monsanto was not a participant in the Suspension Hearings and did not provide background information to EPA.

Chrysler (Ref. 5-17), Saab-Scania (Ref. 5-33), and General Motors (Ref. 5-45) did provide emission test data for Monsanto base metal/pellet catalysts they had evaluated. The data are summarized in Table 5-23.

5. 7. 8 Oxy-Catalyst

Oxy-Catalyst does not perform vehicle emission tests and therefore relies on auto company data. The tests conducted on their catalysts by the automobile manufacturers consist of engine dynamometer performance tests, car performance tests, and durability tests.

5. 7. 8. 1 Low Mileage Emissions

Oxy-Catalyst's latest catalyst (HN-1429) performance data (Ref. 5-7) are tabulated in Table 5-24.

5. 7. 8. 2 High Mileage Emissions

The latest test results on durability received from GM (Ref. 5-7) for the HN-1429 catalyst show that after 4600 miles, the emissions have increased to 3. 8 gm/mi CO and 0. 36 gm/mi HC. On earlier generations of catalyst,

Table 5-22. Johnson-Matthey Catalyst Data

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
		MGB			x					Noble/Mono: JM	1975	0	0.14	1.02	2.41	Brit. Leyland
		Jaguar XJ-6			x					Noble/Mono: JM	1975	0	0.20	2.50	1.00	Brit. Leyland
467	0B44448	1972 model 144: engine B20F		12/2/71	x					Noble/Mono: JM AEC 3A	1975	100	0.19	1.56	3.32	Volvo
616				1/11/72						Noble/Mono: JM AEC 3A		1,300	0.72	4.28	3.65	Honeycomb Broken
1029	0B50424	1972 model 144: engine B20F		3/17/72	x					Noble/Mono: JM AEC 3A	1975	0	0.17	1.52	2.46	Volvo
1081				3/29/72						Noble/Mono: JM AEC 3A		750	0.17	1.25	2.41	Honeycomb Broken
1102	0B50840	1972 model 144: engine B20F		4/10/72	x	x				Noble/Mono: JM AEC 3A	1975	0	0.31	3.28	0.8	Volvo
2180		W108	4000	2/29/72						Noble/Mono: JM	1975		0.11	2.34	1.14	Daimler-Benz
2245		W108	4000	3/13/72						Noble/Mono: JM	1975		0.13	2.67	0.81	Daimler-Benz
2264		W108	4000	3/16/72						Noble/Mono: JM	1975		0.15	1.72	0.88	Daimler-Benz
4	311	2.0 liter			x					Noble/Mono: JM	1975	0	0.30	1.73	2.23	Saab
												995	0.21	1.95	2.00	Catalyst Loose
5	311	2.0 liter			x					Noble/Mono: JM	1975	0	0.21	2.32	1.95	Saab
												2,520	0.32	4.67	1.75	Catalyst Loose

Table 5-23. Monsanto Catalyst Data

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
1	259	360			x	x			30% Size	Base/Pellet (ECA 302)	1972	0	0.30	4.5	1.39	Chrysler
2												27	0.34	3.5	1.34	
8	314	2.0 liter			x	x				Base/Pellet (Monsanto 404)	1975	0	0.26	3.03	1.10	Saab
												248	-	-	-	Test Continuing
9	385	1.85 liter			x		Elect. Inject			Base/Pellet	1975	0	0.22	1.44	2.37	Saab
												9,750	0.50	2.97	2.87	Test Continuing. Mar Cycle
10	341	2.0 liter					Elect. Inject			Base/Pellet	1975	0	0.31	1.61	1.75	Saab
												2,050	0.61	4.16	1.58	Test Continuing
	1938	Pontiac 455	4500	12/71	x	x	x	x		Base/Pellet (ECA-125)	1975	400	0.41	5.4	1.5	GM
	61125	Buick 455	5000	2/72	x	x	x			Base/Pellet (ECA-125)	1975	2,500	1.0	7.6	0.9	GM
	2828	Buick 455	5000	3/72	x	x				Base/Pellet (ECA-141)	1975	0	0.14	3.8	3.1	GM
	61206	Cadillac 472	5500	2/72	x	x	x	x		Base/Pellet (ECA-125)	1975	1,200	0.51	4.6	0.9	GM
	61329	Chevrolet 402	4500	7/71	x	x	x			Base/Pellet (NBP-70194)	1975	126	0.47	4.0	1.1	GM
				4/72								5,550	0.55	8.8	1.1	
	61201	Cadillac 472	5500	2/72	x	x	x	x		Base/Pellet (ECA-125)	1975	1,000	0.92	6.8	0.9	GM
				3/72								1,500	1.80	8.8	0.8	

Table 5-24. GM Evaluation of Oxy-Catalyst Catalyst (Low Mileage Emissions Data)[a]

Test No.[b]	Emissions, gm/mi[c] HC	 CO
1	0.28	1.7
2	0.20	1.6
3	0.28	3.0
4	0.38	1.7
5	0.32	2.2
6	0.34	2.1
7	0.29	3.3
8	0.41	2.4
9	0.34	2.4
10	0.33	2.5
11	0.33	5.4
12	0.33	3.5
Average	0.32	2.68

Emission results with different fresh catalyst formulations (0 mi) are:

Catalyst	Emissions, gm/mi[c] HC	 CO
1	0.30	5.0
2	0.30	2.7
3	0.30	3.5
3	0.26	2.5
4	0.34	3.9
5	0.20	3.2
6	0.23	2.3
7	0.20	1.9

(a) Prototype vehicle without EGR

(b) These were repeat tests made with a fresh HN-1429 catalyst

(c) 1975 CVS-CH

durability tests of up to 33,000 miles indicate catalyst hot cycle efficiencies decline from 98 percent initially to an average stable level of about 60 percent within the first 15,000 miles (see Figure 5-32). The fuel used in testing contained 0.02 gm/gal lead, 0.004 gm/gal phosphorus, and 0.04 percent by weight sulphur.

5.7.8.3 Comparison with Auto Company Test Data

Data submitted by General Motors (Ref. 5-45) concerning its vehicle test evaluations of Oxy-Catalyst catalysts are shown in Table 5-25.

5.7.9 Union Carbide

Union Carbide did not provide catalyst emission data; no auto company evaluations of Union Carbide catalysts are reported.

5.7.10 Universal Oil Products

5.7.10.1 Emission Data - Low and High Mileage

Universal Oil Products has performed many vehicle tests incorporating catalyst systems. Universal Oil Products (Ref. 5-50) believes that a noble metal pelleted catalyst is one of their best candidates. A durability test of this catalyst on a 1971 vehicle gave the following results:

	Estimated 1975 CVS-CH Emissions, gm/mi	
Mileage	HC	CO
8,000	0.36	1.46
16,500	0.28	0.81
21,933	0.47	2.65

This catalyst failed to meet the emission standards after about 20,000 miles. Universal Oil Products feels this catalyst failed to meet the standards because of attrition from over-temperature conditions. It has since improved the stability of this catalyst which it predicts should reduce this type of attrition.

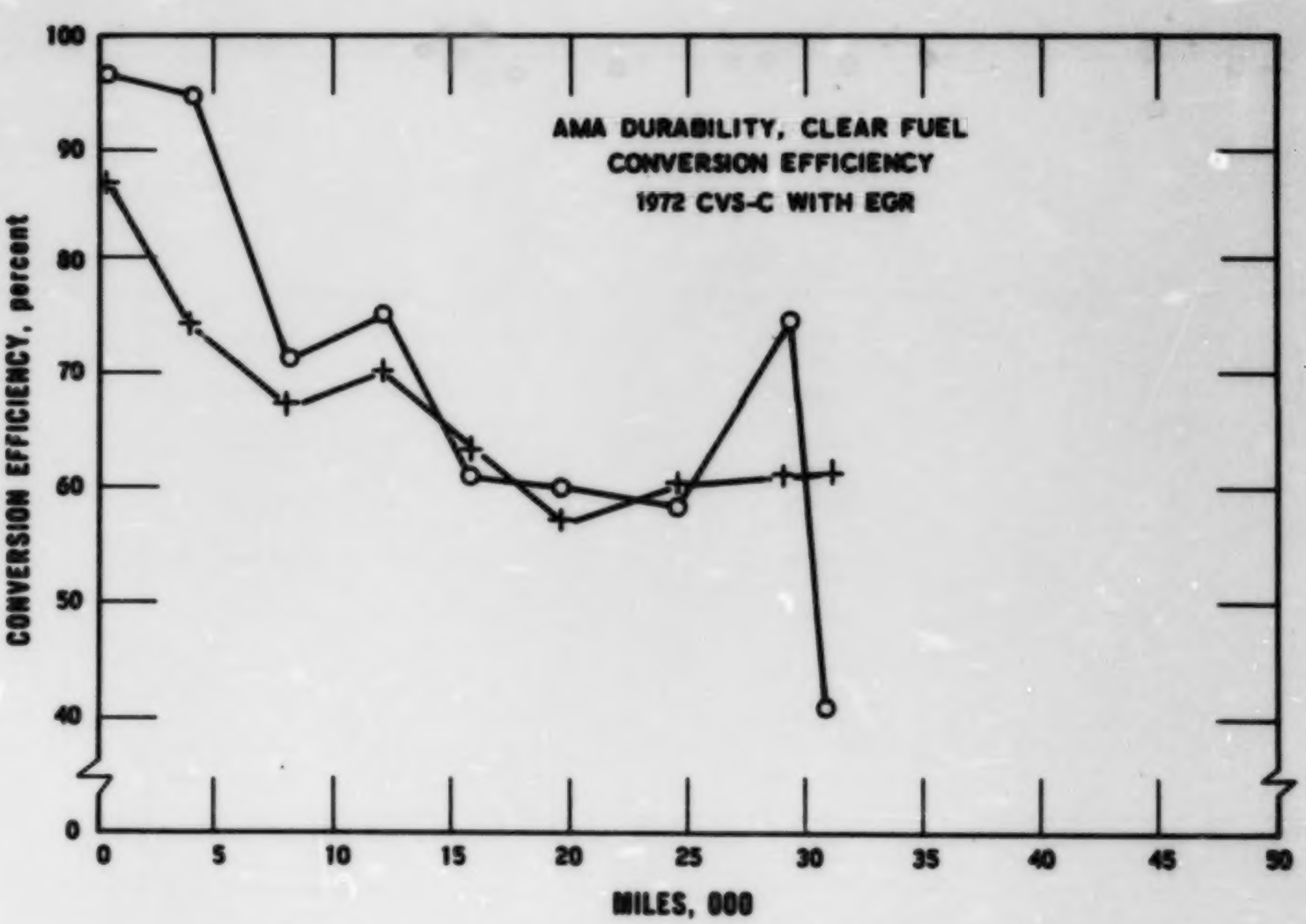

Figure 5-32. General Motors Durability Test of Oxy-Catalyst P-623

Table 5-25. Oxy-Catalyst Catalyst Data

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
	2822	Buick 455	5000	1/72	x	x				Base/Pellet (G-1313)	1975	0	0.41	5.7	3.5	
	2824	Buick 455	5000	1/72	x	x				Base/Pellet (G-1313)	1975	0	0.73	5.0	3.7	
	2825	Buick 455	5000	3/72	x	x				Base/Pellet	1975	0	0.31	4.6	3.3	
	933	Buick 455	5000	11/71	x	x				Base/Pellet	1975	0	0.19	1.8	2.4	
	61317	Chevrolet 350	4500	10/71	x	x	x			Base/Pellet (G-625-71)	1975	0	0.47	6.7	1.4	
				3/72								12,014	1.20	13.6	1.8	
	Dev	Chevrolet 400	5000	12/71	x					Base/Pellet	1975	0	0.19	2.0	5.9	
				3/72								5,566	0.51	9.4	5.3	
	2541	Oldsmobile 350	5000	3/72	x	x	x			Base/Pellet	1975	9	0.17	2.7	2.2	
				4/72								3,103	0.46	7.1	2.1	
	2494	Oldsmobile 455	5000	1/72			x			Base/Pellet	1975	0	0.25	9.2	3.2	
				4/72								4,280	1.02	7.7	3.3	
	2249	Oldsmobile 455	4500	1/72		x	x			Base/Pellet	1975	54	0.27	10.8	1.7	
				4/72								6,400	0.48	11.9	1.3	
	2850	Oldsmobile 455	5500	1/72		x	x			Base/Pellet	1975	0	0.31	10.5	2.0	
				4/72								15,000	0.58	7.4	2.7	
	4231	Buick 350	4500	2/72	x	x	x			Base/Pellet	1975	0	0.64	6.8	2.5	
				4/72								7,600	0.83	5.5	3.7	

Universal Oil Products has also developed a noble metal monolithic oxidation catalyst on which they reported no emission data. Ford is reportedly interested in this catalyst.

The third candidate UOP has developed is a base metal pelleted catalyst on which the following data were reported (Ref. 5-51):

	Baseline emissions[1]	1975 CVS-CH gm/mi Zero miles	 1500 miles	 7722 miles
HC	1.12	0.14	0.19	0.08
CO	12.62	1.21	3.90	1.15

During this test, the CO did rise above the standard at about 1500 miles due to, UOP feels, low temperature sulfur poisoning. Universal Oil Products reduced the air/fuel ratio of the engine at 7180 miles to increase the catalyst temperature. This reversed the deactivation and lowered the CO emissions below the standard.

Table 5-26 summarizes representative emission data for various UOP catalysts, as determined from tests performed by UOP (Ref. 5-51).

5.7.10.2 Catalyst Durability Road Test

Road tests to 25,000 miles on two cars equipped with the noble metal, pelleted catalyst system were recently completed in an EPA sponsored test conducted by Olsen Laboratories (Ref. 5-9). The results of these runs are shown in Table 5-27.

5.7.10.3 Retrofit Applicability

In low mileage tests (under 4000 miles) conducted by UOP (Ref. 5-39), 82 vehicles had emissions which represent an 85 percent reduction of the 90-percent reduction required to meet the 1975 standards. Seven vehicles actually met the 1975 standards. Data for these vehicles are shown in Table 5-28.

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[1] Vehicle without catalyst

Table 5-26. Summary of Representative Catalyst Test Data (from UOP Tests of UOP Catalysts)

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO$_x$	
		1972 Buick Le Sabre		2/72						PZ-214	1975 est	Not known	0.21	2.22	2.91	
		1971 Chev 350		12/71	x					PZ-224-M1 PZ-224-M2 PZ-224-8605	1975 est	0 hr 12 hrs 0 hr 0 hr 12 hrs	0.17 0.25 0.17 0.07 0.20	0.90 2.19 1.35 0.73 1.36		GM converter
		1971 Chev 350		10/71	x					PZ-1-214-2 PZ-1-215-1 PZ-1-221-M1	1975 est	0 hr 0 hr 12 hrs 0 hr	0.15 0.13-0.19 0.24-0.36 0.27	1.77 0.68-1.36 2.0-3.54 1.13		GM converter (75% air
		1971 Chev 350		11/71						PZM-11711 (5" OD x 3" long)	1975 est	0	0.66	5.51		"Monolithic"
		1971 Chev 350		11/71						PZM-7711 (5" OD x 3" long) PZM-9711 (5" OD x 3" long) PZM-10711 (5" OD x 3" long)	1975 est	- - -	0.59 0.53 0.49	1.69 1.35 2.40		
		1971 Ford 351								PZ-195 (in 2 UOP mini-verters) (4.75 x 1.7; 30 in³ bank)	1975 est	 5000 16,500 21,333 21,096	0.19 0.36 0.29 0.47 0.74	1.45 1.46 0.91 2.65 2.46		"Cold" only Noble pellets 20-25% catalyst loss "Hot" only
		1971 Ford 351		12/71						2294-163	1975 est	 2200 12.500	0.92 0.45 1.19	1.07 1.76 1.59		Monolith - "hot" only
		1971 Ford 351		12/71						2294-165	1975 est	0 12.500	0.69 1.07	2.10 1.59		Monolith "Hot" only
		1972 Datsun 510		2/72	x		Fuel rich			PZ-195 PZ-216 PZ-226	1975 est		0.25-0.28 0.22-0.41 0.16-0.24	0.54-2.13 0.78-1.75 0.99-2.0	 2.3-2.9 2.6-3.7	UOP mini-verter 5-3/4" x 1.2" long
		1971 Chev 350		3/72	x					PZ-1-214L-1: aged on 1971 Ford Galaxie	1975	0 4670 4670	0.04 0.14 0.14	1.00 4.91 2.03	2.41 2.33 1.90	GM converter After elevating temp to 1500°F for 30 min
		1971 Chev 350		3/72	x					2441-112	1975	0 1200	0.02 0.11	0.84 2.39	2.63 2.46	GM converter
		Alfa Romeo 2.0 liter (4 cyl.)		3/72						PZ-214 PZ-195 PZ-168 PZ-216	1975 est 1975		0.54 0.38 0.58 0.42	2.45 4.29 5.78 2.60	1.96 2.28 1.52 1.74	80 in³ converter 60 in³ converter
		1971 Capri - 1.6 liter		3/72						PZ-1-216-M2	1975 est	0	0.50	0.69		(1) Mini-verter (4-3/4" x 1.7")
		1971 Capri - 3.0 liter		3/72						PZ-216	1975		3.95	5.50	2.23	(2) Mini-verters (4-3/4" x 1.4")
		1971 Fiat 1.6 liter								PZ-195 PZ-226 PZ-216		0 0 0	0.39 0.23 0.45	0.51 0.37 0.56		(1) Mini-verter (4-3/4" x 1.7")
		1971 Chev 351		4/72	x					PZ-1-214-3: aged	1975	0 7180 2728 15,274	0.14 0.15 0.08 0.10	1.21 5.25 1.15 2.90	1.53 2.52 2.46 3.00	GM converter After 1550°F recycling of bed temperature More recycling
		1971 Chev 350		4/72	x					2424-170 2424-86	1975 est	0 5000 0 5000	0.87 0.54 0.50 0.63	[illegible] 1.50 1.72 1.38	 3.47 3.83	Mono (5" OD x 3" per bank) Mono (5" OD x 3" per bank)

Table 5-27. 25,000 Mile Durability Tests of UOP Mini-Verter with PT-A-S Catalyst (2-1965 Chevrolets, 327 CID)

Car and Mileage Point		Emissions, gm/mi[a]			
		HC		CO	
Car #21[b]					
0 Miles	- Base	9.1		92.1	
	- With Converter	1.9		2.7	
	- Emissions Removed	7.2	(79%)	89.4	(97%)
20,000 Miles[c]	- Base	16.7		199.5	
	- With Converter	5.6		92.8	
	- Emissions Removed	11.1	(66%)	106.7	(53%)
Car #22[d]					
0 Miles	- Base	7.9		65.0	
	- With Converter	1.45		2.3	
	- Emissions Removed	6.45	(82%)	62.7	(96%)
25,000 Miles	- Base	26.85		86.2	
	- With Converter	5.2		16.9	
	- Emissions Removed	21.65	(81%)	69.3	(80%)

[a] 1972 CVS-C test procedure

[b] Unleaded fuel

[c] Test concluded at 20,500 miles. Total vehicle miles were over 100,000 and vehicle deterioration made continuation impractical.

[d] 10 percent of miles on leaded fuel

Table 5-28. UOP Summary of Emission Results for Retrofitted Vehicles (Mileage Less Than 4000 Miles)

Vehicle	Catalyst	Emissions, gm/mi[a]	
		HC	CO
Fiat 85	216	0.40	1.20
Fiat 1600[b]	216	0.36	0.57
Subaru FF-1	195	0.21	2.74
Datsun	216	0.22	0.77
71 Chevrolet	214	0.14	1.21
65 Chevrolet	226	0.32	0.58
71 AMC	195	0.32	1.30

[a] 1975 CVS-CH Test Procedure

[b] Average of two tests

5.7.10.4 25,000 Mile Durability Tests

Five 25,000-mile tests are currently being conducted by UOP; one of these has been completed (Ref. 5-32). The results of this test are shown in Figure 5-8. During the early stages of this test, fuel was alternated between lead-free fuel at about 0.03 gm/gal lead and fuel containing 2.5 gm/gal lead. Good catalyst recovery when operated on lead-free fuel is shown for both HC and CO emissions. At about 19,000 miles, the vehicles were switched to fuel containing 0.05 gm/gal lead and 0.01 gm/gal phosphorus. Catalyst activity, as indicated by emission levels of HC and CO, remained virtually constant over the balance of this 25,000-mile run.

This test indicates the ability of this catalyst to remain active in spite of occasional contamination from fuel additives and with continued operation on fuel at the lead and phosphorus levels suggested in the recent proposed EPA fuel additive regulations (Ref. 5-21).

5.7.10.5 Comparison with Auto Company Test Data

A number of auto companies have provided UOP with the results of testing UOP catalysts. These data are summarized in Table 5-29. Additional emission test data are available from submissions made by the auto companies during the Suspension Hearings. These data are summarized in Table 5-30.

5.7.11 Kali-Chemie

Kali-Chemie was not a participant in the EPA Suspension Hearings. A limited amount of test data for its catalysts are available from Saab-Scania (Ref. 5-33) and Daimler-Benz (Ref. 5-49), as shown in Table 5-31.

5.7.12 Degussa

Degussa was not a participant in the EPA Suspension Hearings. A limited amount of test data for their catalysts are available from Saab-Scania (Ref. 5-33), Daimler-Benz (Ref. 5-49), and General Motors (Ref. 5-45), as shown in Table 5-32.

Table 5-29. Summary of UOP Catalyst Data (Received by UOP from Automakers) (Ref. 5-51)

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description: AI	EGR	Mod. Carb.	EFE	ρTR	Catalyst	Test Proc.	Test Mileage	Emissions, gm/mi: HC	CO	NO$_x$	Remarks
		1972 Isuzu; 110 CID (PA 30D; 4 cyl)		2/72	x				x	PZ-168	1975 1975	0 1400	0.24 0.38	3.61 4.72		UOP low-profile converter; weld crack at 2500 miles
				1/72						PZ-168		0	0.21	1.94		Increased secondary air
		Subaru FF-1; 1.3 liter		2/72						PZ-226	1975	0	0.11	2.6	3.98	Fuji converter
		Toyota; 1.6 liter		12/71	x	x				PZ-214	1975	0	0.21	2.66		Toyota converter
		Mitsubishi Colt		2/72						PZ-214	1975	381 3000	0.89 1.34	3.46 23.7		Mitsubishi converter
		Saab 99EA; 1.85 liter		1/72						PZ-1-214-2	1972		0.67 0.68	7.13 3.19	0.74 1.36	UOP low-profile converter, best carburetor setting 12% leaner setting
				12/71	x					PZ-216	1975	403 1142	0.19 0.23	3.15 2.91	3.77 3.45	UOP mini-verter (4-3/4" x 1.7")
		Mazda 1.6 liter		4/72	x					PZM-17121	1975[a]		0.90	6.15		Monolith
										PZM-17122			0.83	8.00		Monolith
				12/71						PZ-226	1975		0.87	7.6		Toyo Kogyo container
										PZ-214			0.90	10.3		Toyo Kogyo container
				10/71	x					PZ-195	1975[a]	0	0.19	4.2		Mini-verter (18 in^3)
		Saab			x	x				PZ-216	1975	0 4180	0.16 0.39	2.77 4.55	0.98 1.53	Mini-verter (5-3/4" x 1.4")
		Toyo Kogyo Capella 1.6 liter								PZ-226 (Toyo converter)		0 0	0.48 1.34	1.84 15.2		Hot CVS only Cold CVS only
		Mitsubishi								PZ-226	1975	0 8000	0.05 1.14	1.04 25.0		Mitsubishi converter Screen failed, lost catalyst
		Toyota; 1.86 liter								PZ-226	1975	0	0.33	1.57		Toyota converter; 0.32 gm gal lead
		Datsun; 1.6 liter								PZ-226	1975[a]	0	0.25	2.16		Nissan converter
		Mitsubishi		4/72						PZ-216	1975	600 7000	0.14 0.25	2.28 4.33		Mitsubishi converter Screen failure at 8000 mi

[a] Estimated

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Table 5-30. Summary of UOP Catalyst Data Submitted by Auto Makers During Hearings

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description, AI	EGR	Mod. Carb.	EFE	ρTR	Catalyst	CVS Test Proc.	Test Mileage	Emissions, gm/mi HC	CO	NO_x	Remarks
4	637	Chrysler (360) (Ref 5-17)			x				30% Size	UOP	1972		0.8	2.9	3.0	Couldn't control A/F
	D08-6	AM. Motors (360-V8) (Ref. 5-48)	4000							(2) UOP mini-verters	1975	4000	0.39	2.50	3.20	
914 980	OB50424	Volvo 1972 model 144 (Ref. 5-46)								UOP noble pellets	1975	0 195	0.13 0.19	2.74 3.92	3.62 3.23	AC/Delco converter
200	OA34293	Volvo (Ref. 5-46)								UOP	1975	125 375	0.11 0.12	1.23 1.62	2.20 2.15	
602 692	OB44085	Volvo (Ref. 5-46)				x				UOP	1975	0 5852 7000	0.12 0.18	1.69 6.24	1.24 1.26	Reactor breakdown
	General Motors (Ref. 5-45)															
	61355	Chev 350	4000	2/72	x	x	x		x	PZ-2-168 R-5 (Base/Pellets)	1975	700	0.30	2.7	0.8	
	61358	Chev 350	4500	1/72	x	x	x	x	x	PZ-2-168 R-5 (Base/Pellets)	1975	80	0.33	2.4	0.9	
	62504	Pont. 455	4500	11/71	x	x	x		x	PZ-1-224-1 (Base/Pellets)	1975	100	0.34	2.4	0.9	
	9168	Buick 455	5000	3/72	x	x	x		x	PZ-1-225-1 (Base/Pellets)	1975	650	0.31	2.7	1.7	
	8245	Buick 455	5000	2/72	x	x	x		x	PZ-4-214 R-14 (Base/Pellets)	1975	300	0.23	2.8	1.4	
	5274	Buick 455	5000	3/72	x	x	x		x	PZ-4-214 R-14 (Base/Pellets)	1975	300	0.44	2.8	1.5	
	8195	Buick 455	5000	3/72	x	x	x	x	x	PZ-4-214 R-14 (Base/Pellets)	1975	1644	0.25	2.5	1.0	
	61201	Cad 472	5500	1/71	x	x	x		x	PZ-4-214 R-14 (Base/Pellets)	1975	50	0.16	5.9	1.0	
	2014	Olds 350	4500	2/72 2/72		x	x		x	PZ-1-224-1 (Base/Pellets)	1975	85 4552	0.52 0.95	12.0 12.0	2.3 2.4	Discontinued
	2611	Olds 350	5000	1/72 2/72	x	x	x		x	PZ-1-224-1 (Base/Pellets)	1975	1 6145	0.24 1.4	9.1 14.6	1.9 2.6	Lost catalyst
	61420	Olds 455	5000	12/71 4/72	x	x	x		x	PZ-2-168-R-5 (Noble/Pellets)	1975	100 2287	0.20 0.37	2.6 3.2	1.0 1.1	
	934	Buick 455	5000	11/71 3/72	x	x			x	PZ-1-224-1 (Base/Pellets)	1975	0 18132	0.25 1.49	2.7 16.7	2.0 2.9	Backfire damaged muffler
	933	Buick 455	5000	11/71 4/72	x	x			x	PZ-4-214-R-14 (Base/Pellets)	1975	0 46,301	0.19 0.78	1.8 11.7	2.4 2.1	Test stopped
	BAK	Buick 455	5000	11/71 4/72	x				x	PZ-4-214-R-14 (Base/Pellets)	1975	21 12980	0.17 0.36	2.8 6.6	3.7 1.6	

Table 5-31. Kali-Chemie Catalyst Test
(Base Metal/Pellets)

Auto Co.	Test No.	Vehicle No.	Fuel System	Air Injection	EGR	Mileage Type	Mileage	Emissions, gm/mi[a]		
								HC	CO	NO_x
Saab	6	301	El. Inj.	Yes	No	MAR	0	0.23	2.98	2.59
							5,350[b]	0.32	3.38	2.66
Saab	7	301	El. Inj.	Yes	No	MAR	0	0.22	2.85	1.02
							5,900[c]	0.25	3.63	1.96
Daimler Benz	2324							0.10	1.70	0.28

[a] 1975 CVS-CH test procedure

[b] Test continues

[c] Container cracked

Table 5-32. Degussa Catalyst Test Data Base Metal/Pellets)

Auto Co.	Test No.	Vehicle No.	Fuel System	Air Injection	EGR	Mileage Type	Mileage	Emissions, gm/mi[a]		
								HC	CO	NO_x
Saab	12	301	El. Inj.	Yes	No	MAR	0	0.19	2.11	1.66
							2,580[b]	0.74	15.66	2.52
Daimler Benz	2377							0.14	2.3	1.0
GM	2826	Buick 455[d]		Yes	Yes		10	0.38	3.5	3.3

[a] 1975 CVS-CH test procedure

[b] Catalyst poisoned by phosphorus (4 ppm) in fuel

[c] Mileage accumulation route

[d] Degussa catalyst OM 56 ET

5.7.13 Imperial Chemical Industries

Imperial Chemical Industries was not a participant in the EPA Suspension Hearings. However, British Leyland (Ref. 5-23) did provide emission test data for ICI catalysts, as shown in Table 5-33.

5.7.14 AC-Delco

A number of auto companies presented emission test data results they obtained when using AC-Delco converters containing base metal/pellet catalysts. It is not known who supplied the pellets originally. The test data are summarized in Table 5-34.

5.8 OVERTEMPERATURE PROTECTION SYSTEMS

Overtemperature protection systems of several types are proposed to provide against overheating of the catalyst bed, overheating of the vehicle structure, and causing fires. Catalyst bed temperatures normally run in the 1200-1400°F range during normal operation. These temperatures can rise to 1700-1800°F (Chrysler, Engelhard) during high speed driving and when pulling trailer loads. Chrysler points out that catalyst overtemperature can result from a variety of conditions, including, spark plug misfire, turning key off during deceleration, high speed driving, pulling trailer loads, stuck choke, plugged air cleaner, low carburetor float, and fuel boiling due to protracted idling.

Two basic approaches have been suggested by the automotive industry and are under evaluation for providing the necessary catalyst overtemperature protection. Both approaches employ a thermocouple signal to actuate the control device.

One method is to control the secondary air supply to the catalytic converter. Without the necessary oxidizing atmosphere, the catalyst would not function efficiently and generate the normal temperature rise across the bed.

Table 5-33. British Leyland Test Data for ICI Catalysts

Car	Mileage	EGR	Emissions, gm/mi[a]		
			HC	CO	NO_x
Austin Marina (A)[c]	0	No	0.18	2.29	2.33
	6,574	No	0.45	3.00	1.97[b]
	9,200	No	0.20	2.61	2.21
Austin Marina (A)[d]	0	No	0.19	1.38	2.08
	4,500	No	0.25	1.14	2.44

[a] 1975 CVS test procedure

[b] Valve recession, new head fitted after test

[c] Noble/monolith

[d] Noble/pellets

Table 5-34. AC-Delco Converters -- Emission Test Data Summary

Test No.	Car No.	Car and/or CID	Test Weight	Test Date	System Description						Test Proc.	Test Mileage	Emissions, gm/mi			Remarks
					AI	EGR	Mod. Carb.	EFE	TR	Catalyst			HC	CO	NO_x	
	American Motors (Ref. 5-48)															
	D17-11	258-6	3000		x	x				Base/pellets	1975	32,000	0.39	3.04	1.50	Actual test points
	D27-1	360-V8	3500		x	x				Base/pellets	1975	0	0.50	5.01	3.24	
	D11-2	360-V8	4000		x	x				Base/pellets	1975	0	0.39	6.09	2.85	
	D11-3	258-6	3500		x	x				Base/pellets	1975	0	0.23	1.47	2.12	
	D14-2	232-6	3000		x					Base/pellets	1975	0	0.23	2.38	3.28	
	D01-28	360-V8	4000		x	x				Base/pellets	1975	12,000	1.21	16.94	4.33	
	Volvo (Ref. 5-46)															
806	OB44448	1972 Model 144		2/72						Base/pellets	1975	150	0.39	3.50	4.54	
852				2/72						Base/pellets		339	0.38	2.40	4.57	47% pellet loss
732	OB50430	1972 Model 144		2/72						Base/pellets	1975	120	0.24	2.43	3.14	
809				2/72						Base/pellets		3340	0.39	5.75	3.47	30% pellet loss
	International Harvester (Ref. 5-47)															
	158	1100D Travelall V-392		9/71 11/71	x	x				Base/pellets	1975	0 16,000	0.45 0.83	4.4 11.4	2.96 2.59	Suspected inadvertent use of leaded fuel at 4000 miles
				1/72 4/72	x	x				Base/pellets	1975	0 12,000	0.35 0.68	4.53 9.18	2.49 2.29	Converter recharged Still in progress
	393	1110 Travelall V-392		1/72 4/72	x x	x x				Base/pellets	1975	0 20,000	0.35 0.51	4.56 8.76	3.11 3.00	

The other method is to completely bypass the catalytic converter with the exhaust gas. This approach would fully protect the catalyst (if actuated in time), whereas the first approach still exposes the catalyst to the gas temperature of the exhaust flow. Figures 5-33 and 5-34 illustrate one such bypass system arrangement, as denoted by Chrysler for their A335 emission control system (Ref. 5-17). It is designed to route exhaust gases around the converter whenever 1500°F is exceeded.

In addition to these two protection system approaches, other refinements/ devices are also required. Electronic ignition systems are proposed to help eliminate plug misfiring. The converter proper can be located sufficiently far away from the exhaust manifold to reduce inlet gas temperatures. However, the farther away it is, the slower is the warmup of the bed under cold-start conditions. Johnson-Matthey (Ref. 5-13) suggests the use of an air dump-valve during periods of vehicle deceleration to minimize the catalyst bed temperature.

With regard to vehicle structure protection heat shields are proposed for use between the converters and the vehicle. General Motors (Ref. 5-16) proposes insulators on top and bottom of its converter to protect against vehicle overheating as well as "grass fires".

The following illustrates current opinions of various companies relative to the types of overtemperature protection systems proposed for 1975 vehicles:

a. Volvo prefers a warning system only; no bypass (Ref. 5-40).

b. VW has made no selection; a warning system (optical or audible) may be included with perhaps an interlock to prevent starting the car (Ref. 5-52).

c. Nissan is considering both bypass and secondary air control (Ref. 5-53).

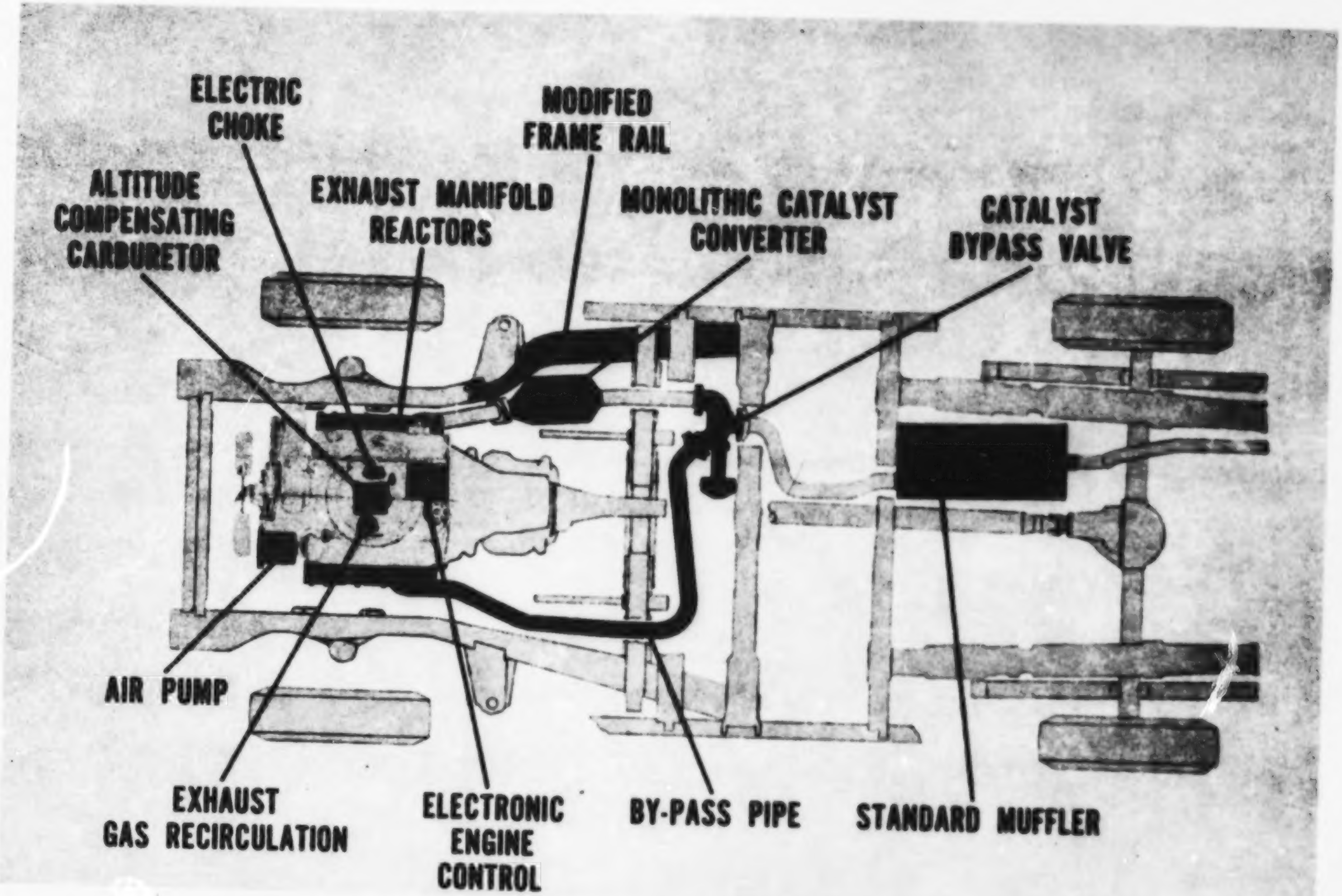
ELECTRIC CHOKE
MODIFIED FRAME RAIL
ALTITUDE COMPENSATING CARBURETOR
EXHAUST MANIFOLD REACTORS
MONOLITHIC CATALYST CONVERTER
CATALYST BYPASS VALVE
AIR PUMP
EXHAUST GAS RECIRCULATION
ELECTRONIC ENGINE CONTROL
BY-PASS PIPE
STANDARD MUFFLER

Figure 5-33. Chrysler A-335 Special Emission Car (System Features)

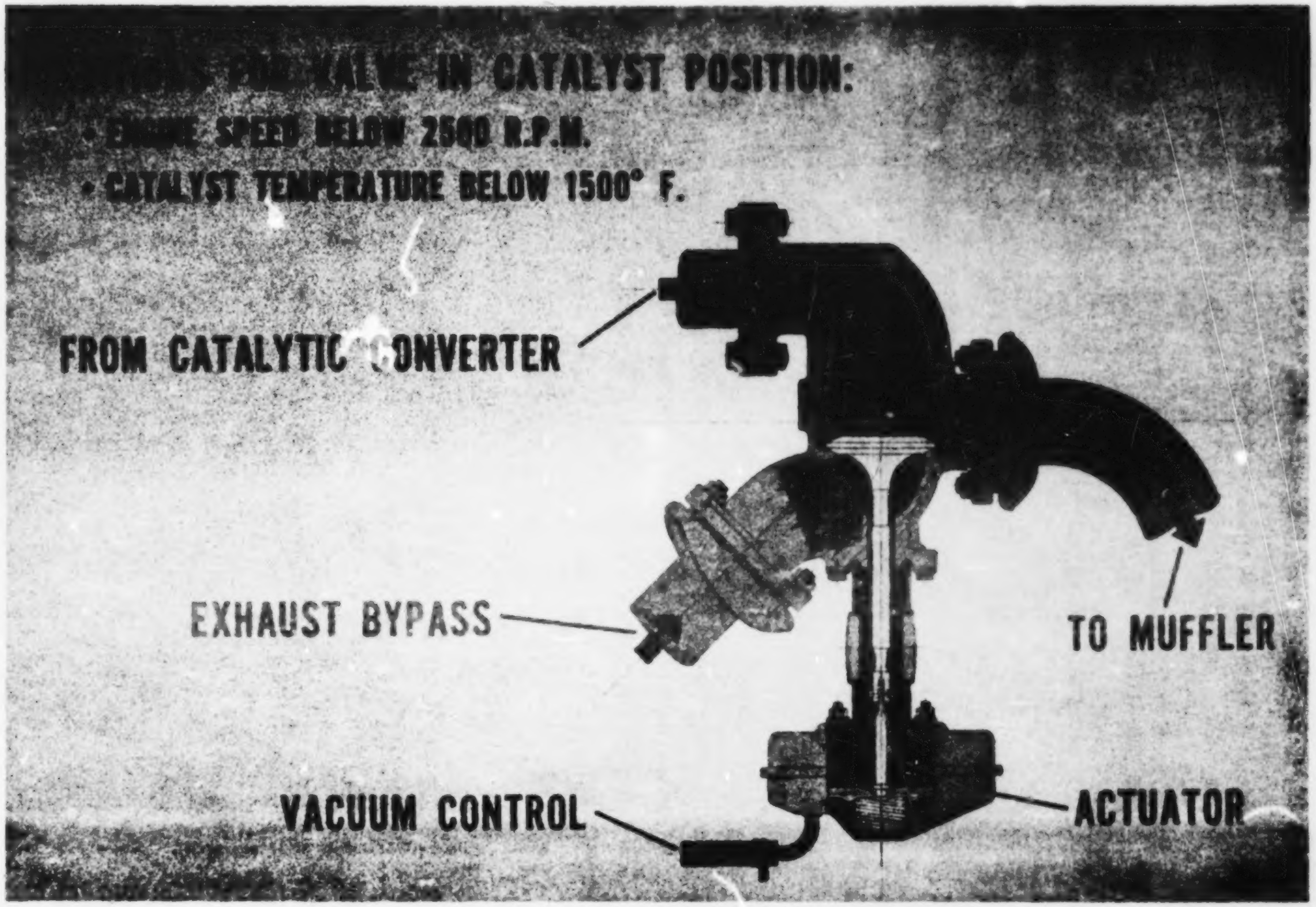
CONDITIONS FOR VALVE IN CATALYST POSITION:
• ENGINE SPEED BELOW 2500 R.P.M.
• CATALYST TEMPERATURE BELOW 1500° F.
FROM CATALYTIC CONVERTER
EXHAUST BYPASS
TO MUFFLER
VACUUM CONTROL
ACTUATOR

Figure 5-34. Chrysler Catalyst By-pass Valve

d. British Leyland prefers not to use bypass (although it has used an experimental system); it utilizes thermocouples, warning lights and buzzers (Ref. 5-54).

e. GM has no bypass in its present plans; it incorporates a choke which fails in the open position; it may use devices in fuel metering and air flow devices to solve downhill coast problems (Ref. 5-34).

f. Ford prefers to cut off the air supply to the converter (using thermocouple for signal) (Ref. 5-35).

g. Chrysler has discarded air cut-off or air bypass to a certain extent; it is developing a full bypass system (Ref. 5-17).

5.9 PROJECTED MAINTENANCE AND REPLACEMENT PROCEDURES

Engelhard reports (Ref. 5-18) that its converters are presently designed to be welded into the exhaust system. Firm details on other systems have not been provided by other companies. Potential users of monolithic catalyst beds have envisioned converter designs which enable simple cartridge-type replacement of the monolithic bed.

In the past, potential users of converters incorporating pelletized catalyst beds projected the eventual possibility of being able to withdraw used pellets from the converter (by vacuum means, etc.) and insert fresh or new pellets. CHEMICO (Ref. 5-3) has now proposed the "topping off" of a converter which has a reservoir of pellets above the pellets actually in use (similar to hydraulic brake fluid reservoir); the topping-off would be accomplished at regular servicing intervals.

UOP states (Ref. 5-39) that the spherical pellets used in their Mini-Verter can be removed and replaced in a matter of minutes (comparable to an oil change).

In all cases, these are mere projections at the moment, with demonstrated automotive application capability lacking. The exact method of catalytic converter replacement or refurbishment must await final selection of catalyst material, final design of the converter canister, and evaluation of replacement or refurbishment alternatives.

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6. THERMAL REACTORS

6.1 SUMMARY DISCUSSION

The thermal reactor is a high-temperature chamber which replaces the conventional engine exhaust manifold. Hot exhaust gases from the engine enter the thermal reactor, which is sized and configured to increase the residence time of the gases and permit further oxidation reactions, thus reducing the HC and CO concentrations.

In general, the thermal reactor embodies a double-walled insulated configuration, with exhaust port liners to conserve the sensible heat in the exhaust gas and to direct the flow to the inner-core section of the reactor. In some instances, baffles and/or swirl plates are used to promote mixing. Illustrations of two reactor designs, the DuPont Type V and the Esso RAM are shown in Figures 6-1 and 6-2.

Whereas both rich and lean reactors have been considered and evaluated for use in 1975 emission control systems, all of the reactors presently being tested as potential 1975 candidate devices are designed for fuel-rich engine operation. These systems require the addition of secondary air (usually injected at the engine exhaust port) to promote the oxidation reactions in the reactor.

With the exception of Toyo Kogyo, no manufacturer proposes to use a full-size thermal reactor device as a first-choice system component for 1975. The General Motors and Chrysler systems utilize a partial (i.e., a small, simplified) reactor which serves primarily as a quick-heat device for rapid warm-up of a catalytic converter. The Toyo Kogyo reactor is a prime emission control component for this manufacturer's rotary engine system; in

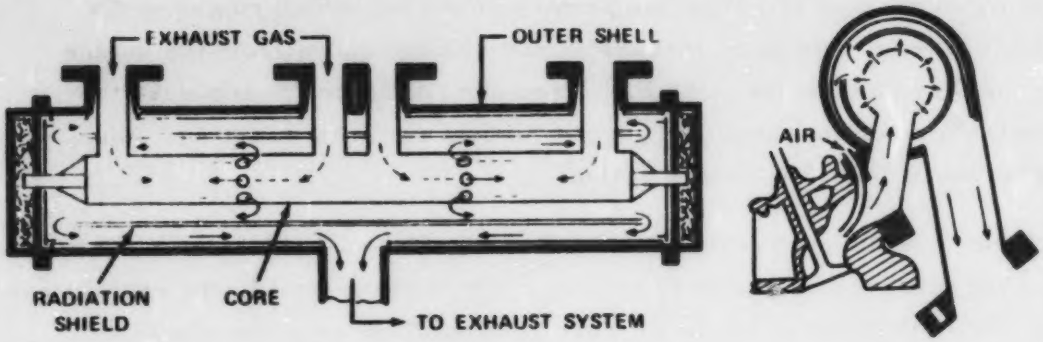
EXHAUST GAS
OUTER SHELL
AIR
RADIATION SHIELD
CORE
TO EXHAUST SYSTEM

Figure 6-1. DuPont Type V Thermal Reactor

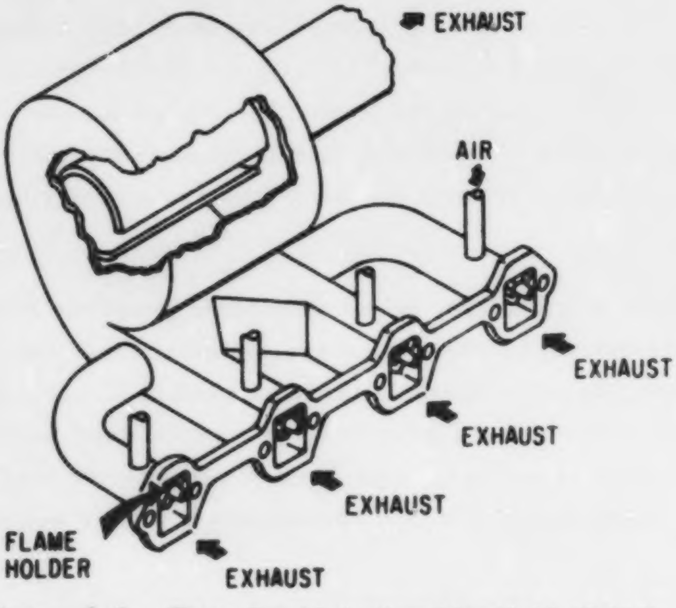
EXHAUST
AIR
EXHAUST
EXHAUST
EXHAUST
FLAME HOLDER
EXHAUST

Figure 6-2. Esso Rapid Action Manifold (RAM) Reactor

addition, it is one of several systems being evaluated for use on the Toyo Kogyo 1975 reciprocating engine. Several manufacturers are evaluating reactor devices as 1975 alternate system components.

Thermal reactor problems identified by the various manufacturers encompass the following: (a) lack of sufficient emission control capability. (b) packaging difficulties, (c) excessive underhood temperatures, and (d) lack of sufficient reactor durability. In addition, durability problems continue to plague the secondary air injection system. Numerous air pump replacements have been reported by a number of manufacturers during the course of reactor durability testing.

Severe engine damage has been caused by reentry of metal oxide particles from the reactor core material through the EGR system into the engine lubricating oil. Such a problem was encountered in the DuPont test vehicle fleet assigned to the California Air Resources Board for evaluation. DuPont is currently investigating improved reactor core materials. A recent study by Ford implies that a basic incompatibility may exist between thermal reactors and catalytic converters when used together. Material deposits have been found in the catalyst which are thought to originate in the reactor liner. These deposits may contribute to the excessive deterioration observed in a number of thermal reactor/catalytic converter emission control systems.

6.2 SPECIAL DESIGN FEATURES

6.2.1 American Motors

The use of a thermal reactor has been investigated by American Motors as a possible alternate system. However, this manufacturer was unable to reach the low level of emissions achieved with the catalytic converter system. This fact, in combination with the major revisions to the vehicle front end that would be required to accommodate the device, has resulted in a decision to confine the 1975 development effort to a catalytic converter system (Refs. 6-1, 6-2).

6.2.2 Chrysler

Chrysler has abandoned thermal reactors as a prime first- or second-choice emission control system primarily because of lack of emission control potential and high-temperature material problems. The 1975 first-choice system will utilize a partial thermal reactor which will function primarily to accelerate the warm-up of the catalytic converter under cold start conditions. The Chrysler partial reactor is approximately one-third the volume of a full-size DuPont-type system; further oxidation reactions are sustained in the downstream catalytic converter. The reactor design incorporates stainless steel liners to help maintain high exhaust gas temperature and to promote mixing and burning of the combustibles with the secondary air injected into the exhaust ports.

Chrysler is looking for new lower cost core alloy materials with less nickel content, but believes that it is two or three years away from a demonstration of 50,000-mile durability (Refs. 6-3, 6-4, 6-5).

6.2.3 Ford

Initially, Ford's first-choice system for 1975 was a combined thermal reactor/ catalyst system. Based on work during the past year, however, Ford believes that the first-choice system ultimately will be a catalyst-only type. Emission results with this system are nearly as good as those for the combined reactor-catalyst system. The slight advantage in emission performance which the reactor-catalyst system may provide is not considered commensurate with the cost increase involved. A final first-choice system selection will be made on completion of the Riverside test program when additional data on comparative system performance will be available (Ref. 6-6).

The test series of 32 vehicles being conducted at Riverside includes eight vehicles (Group II) that incorporate exhaust manifold reactors which function primarily as preheaters for the catalytic converter. The Group II tests are scheduled for completion in October 1972. Data for 4000 miles reported for the Group II vehicles to data are presented in detail in Section 2.2.3.

The effect of long-time exposure of components and materials to the thermal reactor environment is being evaluated. A recent Ford experimental investigation identified material deposits which are thought to originate in the stainless steel liner of the reactor. Investigations are under way to resolve this issue. Ford speculates that a basic incompatibility may exist between thermal reactors and catalytic converters used in combination.

Development reactors tested on six vehicles in the Ford 1975 model year durability test program exhibited four failures at mileages ranging from 5000 to 30,000 miles (Ref. 6-6).

6.2.4 General Motors

Problems of temperature, space, and durability, as well as unsatisfactory emission performance, have led General Motors to discard the thermal reactor as a primary system for meeting the 1975 standards. Possible applications of the thermal reactor to some specific vehicle models are being evaluated.

Limited studies on combinations of a manifold reactor and catalytic converters have been conducted. General Motors reports that a few experimental systems show promise of low emissions at levels at or below 1975 standards. These systems are not ready for production because of problems related to both subsystems which remain to be solved.

General Motors reports that the primary potential application of the thermal reactor system is the Vega vehicle. Emission levels obtained with a Vega equipped with a thermal reactor and EGR were reported to range from 0.2 to 0.24 gm/mi HC, 2.8 to 3.0 gm/mi CO, and 0.39 gm/mi NO_x (see Section 2.2.4).

Problems encountered with the General Motors manifold reactor concern driveability and packaging. The need for extensive insulation to maintain hi oxidizing temperatures (1500° to 2000°F) affects the problem of engine compartment packaging. More experience in the use of high-efficiency insulation materials is said to be needed. Air requirements for the thermal reactor exceed those for the catalytic converter; a larger air pump is therefore required. Satisfactory materials for manifold reactor durability have not yet been found.

When questioned on its emission test results with a thermal reactor on a rotary engine, General Motors was unable to provide any reason why emissions achieved by Toyo Kogyo were significantly lower (Refs. 6-7, 6-8).

6.2.5 International Harvester

International Harvester is considering the use of a thermal reactor on two alternate-choice systems for 1975. The first consists of a thermal reactor, EGR, and advanced fuel system with fast-heat manifold. All development testing has been carried out on the 5500-lb inertia weight Travelall vehicle. Representative CVS-CH emission levels for this vehicle were reported to be (in grams per mile):

HC	0.37 to 1.0
CO	14.8 to 22.3
NO_x	1.2 to 2.8

Durability testing of this system was conducted to 24,000 miles, at which time the reactor was removed for inspection. The left reactor core runners were found to be eroded and the core assembly severely warped. High underhood temperatures resulted in ignition wire failures at 20,000 miles. Detailed emission levels at intermediate mileage points for this vehicle are shown in Section 2.2.5 (International Harvester alternate-choice systems).

A second vehicle, also durability-tested to approximately 26,000 miles (see Section 2.2.5) with the thermal reactor system, exhibited deterioration in CO emission control at 25,794 miles (from an initial value of 14.8 gm/mi to a final value of 42.3 gm/mi). The reasons for this are currently being investigated. Intermediate mileage points were not reported. It was concluded by International Harvester that the CO control with thermal reactors was inadequate. Reactor casting life was reported as "unacceptable" (cracking at 2000 to 4000 miles).

Another alternate system, composed of a thermal reactor, catalytic converter, EGR, air injection, and engine modifications, was tested on the Travelall vehicle. International Harvester reported "representative" emission levels of 0.63 gm/mi for HC, 3.5 gm/mi for CO. and 0.77 gm/mi for NO_x. No details regarding test mileage, converter type, or other specific information were provided (Refs. 6-9, 6-10).

6.2.6 British Leyland

British Leyland's approach has been directed toward the development of a 1975 emission control package which, with the add-on of a reducing catalyst, would meet the standards for 1976. A thermal reactor was considered but was rejected when it was concluded from experimental investigations that a thermal reactor/EGR system would be unable to meet the 1976 NO_x standards. British Leyland indicated, however, that thermal reactor work is being pursued in conjunction with Associated Octel and with Engineering Research and Application, Ltd. (Ref. 6-11).

6.2.7 Daimler-Benz

Development effort with thermal reactors, both singly and in conjunction with oxidation catalysts, was conducted by this manufacturer in three of seven systems under consideration. However, thermal reactors are not used in its first-choice or alternate 1975 candidate systems, and no details on thermal reactors were provided (Ref. 6-12).

6.2.8 Nissan

The Nissan second-choice system uses a thermal reactor in addition to an HC/CO catalytic converter, EGR, air injection, and engine modifications.

Table 6-1. Saab Thermal Reactor Systems

Test No.	Car No.	Reactor Type	Reactor Mileage	Emissions, gm/mi[a]			Remarks
				HC	CO	NO_x	
13	209[b]	DuPont	0 3400	0.20	3.6	1.3	No EGR. 7% power loss. Emissions reported unchanged from 0 mile results.
14	209[c]	DuPont	0 12992	0.41 0.26	14.56 13.27	1.23 3.03	No EGR. 7% power loss. Frequent cracking and leakage. Plug wires burned. Test continuing[d].
15	427	Esso RAM	160	0.12	3.24	1.32	Best result, optimization testing. Use of EGR not specified. Durability test to be started.
16	221[b]	Saab-Scania	0 1500	0.65	7.82	1.03	No.EGR, Electr. fuel injection Not tested, tremendous cracking and sealing problems.

[a] 1975 CVS-CH test procedure.

[b] Normal driving cycle.

[c] MAR driving cycle.

[d] Reactor stripped and rebuilt at frequent intervals. Air pump replaced at 12, 992 miles.

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Specific problem areas itemized were: (a) failure to achieve reduction of CO to required levels, (b) thermal expansion (reactor-to-cylinder block), (c) high fuel economy loss of 10 to 15 percent, (d) power loss up to 10 percent, (e) overheating of the reactor, and (f) high temperatures in the vicinity of the reactor (Ref. 6-14).

6.2.10 Toyo Kogyo

Toyo Kogyo is fairly optimistic that the 1975 standards can be met with a thermal reactor system similar to the design currently installed on their rotary engines. It plans to establish final production design specifications for 1975 vehicles in October 1972.

Three vehicles with 70-CID rotary engines have been tested at low mileage (300-1000 miles). Emission data based on the average of 18 tests on the three vehicles, using the 1975 Federal test procedure, were 0.17 gm/mi HC, 2.2 gm/mi CO, and 0.93 gm/mi NO_x. This is discussed in greater detail in Section 2.2.17 as the Toyo Kogyo first-choice system for the 1975 rotary engine vehicle. General Motors has indicated that its emission test results with a reactor-equipped rotary engine were significantly higher than those of Toyo Kogyo.

Because the 1975 reactor will operate at a temperature about 130°F higher than the 1972 production model, durability of the 1975 reactor must be confirmed. The possible adverse effects of the thermal environment on various underhood components must be determined.

It is anticipated that fuel consumption will increase by about 5 percent over the 1972 models. Fuel with lead concentrations currently on the market is not considered to pose severe durability problems, although, in general, the lower lead content fuel is preferred from the durability standpoint.

With its reciprocating piston engine, Toyo Kogyo is conducting development work on a thermal reactor system, a catalyst system, and a combination system of the two. These are discussed in greater detail in Section 2.2.17 as candidate first-choice systems for Toyo Kogyo.

Recent data on two test vehicles with 110-CID reciprocating piston engines equipped with thermal reactors and tested between 300 to 1100 miles achieved average emission levels of 0.15 gm/mi HC, 2.6 gm/mi CO, and 2.3 gm/mi NO_x, based on an average of six tests on the two vehicles.

Use of the thermal reactor is seen as having particularly severe underhood effects as compared with the rotary engine, because the reciprocating engine occupies a larger volume in the engine compartment (Refs. 6-15, 6-16).

6.2.11 Toyota

No thermal reactor is envisioned for 1975. A thermal reactor is planned for installation ahead of an HC/CO catalytic converter for 1976.

Toyota indicated that the thermal reactor performance goals (unspecified) have nearly been met, but major unresolved problem areas remain, including poor material durability and heat resistance and the need for further development of the secondary air control system to prevent reactor overheating. Toyota also felt that heat from the thermal reactor may cause vapor lock in the brake system (Refs. 6-17, 6-18).

6.2.12 Volkswagen

Volkswagen indicates that it has had numerous problems with thermal reactors. Due to the horizontally opposed cylinder arrangement of the Volkswagen engine, the system requires two reactors or, alternately, extremely long exhaust port extensions.

Volkswagen's recent test results indicate that the 1975 emission standards cannot be attained with thermal reactors alone. Therefore, the reactors are being used principally to provide faster warmup of the catalytic converters used as a component in the Volkswagen emission control systems (Ref. 6-19).

6.2.13 Volvo

Volvo's fourth choice for a 1975 system includes a thermal reactor for HC/CO control. A turbulent reactor designated as Type 4 (modified) has been selected for vehicle evaluation and the best (low mileage) results obtained are shown in Table 6-2.

The problems reported by Volvo for the thermal reactor system are high fuel penalty (about 50 percent increase in fuel consumption), poor driveability, loss of performance, and mechanical failures (Ref. 6-20).

6.2.14 DuPont

The DuPont reactor is a conventional cylindrical design consisting of a cast-iron outer shell which houses a tubular core and shield to reduce heat loss. The latest design configuration, referred to as the Type VIII reactor, recently was designed for the V-8 engine and is the same physical size as the older Type V version but external insulation is used, instead of internal heat shielding, to maintain high reactor temperatures. The Type V reactor is illustrated in Figure 6-1.

The DuPont emission control concept comprises the thermal reactor types described above, along with EGR and a trapping system to remove lead particulates from the exhaust gas. Recent emission tests of this system installed in 4- and 8-cylinder engine vehicles were reported in Refs. 6-21 and 6-22. The data, which were based on the 1975 CVS-CH procedure, are summarized in Table 6-3. It may be seen that the system does not meet the 1975 standards for CO.

Table 6-2. Volvo Thermal Reactor (VFM 80) Emission Results

Test No.	Car Reg. No.	Air/Fuel Setting Percent	Reactor Mileage at Test (Miles)	Emissions, gm/mi CO	HC	NO_x	Test Procedure Year	Remarks
656	OB 48503	+10[a]	0	1.92	0.29	2.13	1975 CVS-CH	Without EGR
721	Automatic Transmission	+10[a]	100	4.09	0.20	1.58		
744		+10[a]	140	2.61	0.09	1.92		Air pump ratio 1.26
752		+10[a]	170	2.09	0.19	2.40		Air pump ratio 1.5
1000		+10[a]	590	1.58	0.12	1.36		With EGR

[a] Cold start enrichment disconnected at 600°C exhaust temperature from reactor. Full load enrichment disconnected.

Table 6-3. DuPont Reactor System Emission Results

Engine Type	Emissions, gm/mi(1) HC	CO	NO_x	Remarks
4-Cylinder(2)	0.29	5.2	0.6	
	0.32	5.2	0.55	
	0.18	4.7	0.58	
	0.18	4.7	0.70	
V-8(2)	0.20	6.0	0.70	Average of DuPont tests
	0.18	7.2	0.52	Outside lab - 2-Test Average
	0.22	7.1	0.58	EPA Test average

(1) 1975 CVS-CH test procedure.

(2) Unidentified U.S. manufactured cars.

DuPont states that the V-8 fuel economy was decreased by 14 percent and the 4-cylinder's by 17 percent compared to standard production models when driven over the road in a mixed city suburban course. Full-throttle performance of the V-8 was not affected relative to the standard production model; acceleration of the 4-cylinder engine vehicle was impaired by the necessity of using EGR at full throttle to achieve low NO_x emissions.

With regard to emissions durability, DuPont states that thermal reactors have been shown to control HC and CO with essentially no change in emission levels for the life of the vehicle.

The physical durability of systems equippped with the DuPont reactor is a question that apparently is not yet resolved. A six-vehicle test program conducted by the State of California in 1970 was terminated at 20,000 miles because of excessive wear of the timing chain and valve train caused by metal oxide particles from the reactor core being taken through the EGR system into the lubricating oil.

Based on engine dynamometer tests, DuPont believes that reactor cores fabricated of Inconel 601 would be more oxidation-resistant than 310 stainless steel and would operate satisfactorily for the lifetime of the car. However, DuPont has not yet tested Inconel 601 on vehicles.

It was indicated that damage has been observed in electrical and plastic components under the hood due to the heat generated by the thermal reactors (Refs. 6-21, 6-22).

6.2.15 Esso

The most recent Esso thermal reactor development is referred to as RAM (Rapid Action Manifold). The reactor (Figure 6-2) consists of a torus made of Type 310 stainless steel. Connecting arms lead exhaust gases from the engine to the torus. The gases flow around the torus and exit through a slot into a central plenum and then into the exhaust pipe. The slot is positioned so that the gases must flow at least half-way around the torus before they can exit, and so that a portion of the circulating gases flows completely around the torus to mix with the entering engine exhaust. Air is injected into each engine exhaust port and is aimed toward the valve. Most of the thermal reaction takes place as the gases swirl through the reactor. Flameholders are located at the exit of each engine exhaust port; they act to stabilize the flame at the exhaust port outlets during start-up, when the engine is choked.

Esso results for the RAM system are quoted as follows (Ref. 6-23):

	1972-CVS-C Emissions, gm/mi		
	HC	CO	NO_x
Without EGR	0.07	4.2	1.89
With EGR (12%)	0.08	3.7	0.72

These and other Esso tests of the modified RAM concept were intended to be demonstrative only; no durability tests have been made. If this concept were tested for durability, a more adaptable material than the Type 310 stainless steel used in the demonstrator model would be required.

6.2.16 Ethyl

The Ethyl Corporation has been actively pursuing the development of lead-tolerant emission control devices. This effort has evolved a combination of emission control devices referred to as the Ethyl Lean Reactor System, which includes a full-size lean thermal reactor for HC and CO control, an EGR system for NO_x control, and advanced carburetion for engine operation at the selected lean air-fuel ratio (approximately 17.5) provided by a specially developed, high-velocity carburetor. Spark advance characteristics in the Ethyl system are tailored to provide the best compromise among fuel economy, driveability, and low emissions.

Ethyl has demonstrated this approach with vehicle tests. All test work reported has been done with fuel containing approximately 3 gm/gal of lead. With use of this fuel, the Ethyl Lean Reactor System avoids fuel economy penalties incurred by lowering compression ratio to accommodate low-octane fuels. Ethyl states that the retention of a high-compression ratio also makes it possible to operate with satisfactory driveability at leaner mixtures than otherwise would be the case, and minimizes problems of EGR with respect to vehicle driveability effects.

The most advanced versions of the Ethyl Lean Reactor System are embodied in several Pontiacs and one 1971 Plymouth. Emissions of two of these cars, based on the single-bag CVS test procedure, are shown in Tables 6-4 and 6-5. Similar data obtained with the CVS-CH test procedure for the 1971 Plymouth are compared with the single-bag data in Table 6-4. As can be seen, the HC and CO emissions exceed the 1975 standards. The NO_x emissions are well below the 1975 standard.

Further improvements proposed by Ethyl which could reduce HC and CO emissions include moderation of the amount of air injected during the first few minutes of warm-up operation to increase exhaust oxidation during the choking period; design changes to improve heat conservation in the exhaust ports and exhaust port liners; improvements in the intake manifold to promote quicker warm-up; alterations in transmission characteristics to accelerate warm-up; use of higher compression ratio to permit still leaner mixtures and better utilization of EGR; and use of charcoal absorber traps to reduce HC exhausted during engine startup.

These are logical technical approaches, but until they are incorporated and demonstrated, this concept is considered deficient with regard to meeting the 1975 HC and CO standards (Ref. 6-24).

Table 6-4. Ethyl Lean Reactor--Emission Data for 1970 Pontiac (Vehicle 766)

Vehicle Description	Modifications
1970 Pontiac LeMans 400 CID Engine Automatic Transmission Power Steering Power Brakes	3-Venturi Carburetor EGR System Exhaust Manifold Reactor Exhaust Port Liners Evaporative Loss Controls Exhaust Cooler Units Particulate Trapping Device Air-Injection Pump (Operates During Choking Period) Transmission Modifications (Modulator and Governor)

1972 CVS Procedure

Run Date	HC (gm/mi)	CO (gm/mi)	NO_x (gm/mi)
4-5-71	0.74	7.3	1.40
4-6-71	0.75	7.0	1.60
4-19-71	0.74	5.3	1.70
4-20-71	0.78	6.2	1.70
4-21-71	0.84	6.2	1.48
4-22-71	0.82	5.9	1.45
6-3-71	0.88	6.5	1.45
6-24-71	0.73	6.8	1.40
Avg.	0.79	6.4	1.52
12-18-70	0.64	9.1	1.09

1970 7-Mode Procedure

Run Date	HC (ppm)	CO (%)	NO (ppm)
4-8-71	19	0.21	226
4-13-71	20	0.20	200
4-14-71	.23	0.21	197
Avg.	20.7	0.21	208
Equivalent gm/mi	0.26	5.0	0.81

Table 6-5. Ethyl Lean Reactor--Emission Data for 1971 Plymouth (Vehicle 18M-448)

Vehicle Description	Modifications
1971 Plymouth Fury III 360 CID Engine Automatic Transmission Power Steering Power Brakes Air Conditioning	3-Venturi Carburetor EGR System Exhaust Manifold Reactor Exhaust Port Liners Evaporative Loss Controls Exhaust Cooler Units

1972 CVS Procedure (Single-bag tests)

Run Date	HC gm/mi	CO gm/mi	NO_x gm/mi
2-26-71	1.00	8.0	1.6
3-2-71	0.74	7.3	1.7
3-8-71	0.92	7.6	0.86
3-24-71	0.82	10.0	1.5
4-8-71	1.00	10.0	1.23
Avg.	0.89	8.6	1.37

1975 CVS Procedure (Three-bag tests)

	HC gm/mi	CO gm/mi	NO_x gm/mi
	0.52	6.2	1.37

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7. SECONDARY AIR SUPPLY

7.1 SUMMARY DISCUSSION

Although secondary air injection at engine exhaust ports has been widely used as an independent control device for the suppression of HC and CO emissions since 1966, it is not being given serious consideration by any automobile manufacturer as a prime system for meeting 1975 standards.

In aftertreatment devices for HC and CO control, such as catalytic converters and thermal reactors, sufficient oxygen is needed to promote oxidation of the pollutants. The oxygen required is provided by an engine-driven air pump.

The production hardware for the current air injection system typically consists of an engine-driven air pump, hoses, steel tubing manifolds to deliver the air to each exhaust port, and a series of valves to prevent backfiring and backflowing and to provide relief to the pump when the engine is operating at high speeds and peak loads. In most systems, the belt-driven air pump provides air flow modulation solely on the basis of engine RPM and neglects the demand variation due to throttle setting. A number of manufacturers are investigating the use of fully modulating electric drives or air by-pass techniques for advanced control systems.

Generally, little more than passing mention of the use and type of air pump drives was made by the automobile manufacturers in discussing their projected 1975 emission control systems. Pump durability and pump noise are frequently identified as problem areas; the durability problem appears to be particularly troublesome. However, no manufacturer classifies any part of the air injection system as critical for 1975.

Fuel economy and power-loss penalties associated with the operation of air injection systems are negligible.

In the following paragraphs, the absence of an entry for a given manufacturer indicates that specific information concerning air injection system components was not provided.

7. 2 SELECTED SYSTEMS, BY MANUFACTURER

7. 2. 1 Chrysler Corporation

The Chrysler system for 1975 includes an oxidation catalytic converter and a partial thermal reactor (Ref. 7-1). The secondary air is supplied by a 26-cubic-inch-per-revolution air pump. The previously used 19-cubic-inch pump was required to operate at a speed too high for satisfactory pump life. A drive ratio of 1. 52:1 has been used in the Chrysler integrated system tests.

7. 2. 2 Ford

Secondary air will be used with Ford's current first-choice system, which utilizes a catalytic converter (Ref. 7-2). In 1971, Ford conducted high-mileage tests of six vehicles equipped with 1975-type air injection systems. Secondary air pump failures occurred in four of these vehicles at mileages ranging from 5000 to 35,000. However, Ford does not regard the air pump as a significant problem component.

7. 2. 3 General Motors

General Motors has used a 19-cubic-inch-per-revolution pump extensively in production vehicles and feels it has demonstrated satisfactory performance and reliability. All current installations are driven directly by the engine through a conventional V-belt arrangement. Most applications have a drive ratio of about 1. 2:1 (Ref. 7-3).

The catalytic converter requires approximately 30 percent more air than is currently delivered. Use of the 19-cubic-inch pump would require drive ratios of approximately 2:1. Durability at speeds in excess of 6000 RPM, which would be needed, is limited. In addition, new noise problems are introduced at high speeds. The approach considered for 1975 includes a larger displacement pump with drive ratios which could differ for particular vehicle applications.

Air will continue to be introduced near the exhaust ports. The prior experience of General Motors with its Air Injection Reactor System (AIR) has shown this to be the optimum location, and experiments with oxidation catalysts have not established a more desirable location.

7.2.4 Volvo

The use of secondary air is contemplated for all four of Volvo's alternate 1975 systems (Ref. 7-4). A program to develop a secondary air supply system was initiated in 1970. The system may include a temperature sensor in the converter or reactor and a valve for shutting off or by-passing the secondary air. The research and development phase is reported to be 80 percent completed and engineering testing is in the initial stages.

Pump noise and deterioration of air flow control due to wear of valves and seals, as well as failure of the temperature sensors caused by vibration, are the main problems in Volvo's air supply system.

7.2.5 British Leyland

British Leyland will use air injection systems similar to those installed in its 1972 model year vehicles. The existing air pump capacity is insufficient for the 1975 catalytic converter systems, and modified designs are being investigated (Ref. 7-5).

7.2.6 Daimler-Benz

Daimler-Benz' first-choice system includes an oxidation catalyst, air injection, and EGR. This manufacturer is having air pump durability problems and has recently engaged a new supplier who is working to improve durability (Ref. 7-6).

7.2.7 Saab-Scania

Saab-Scania reports that AC-Delco or Lucas rotary vane-type secondary air supply pumps with V-belt drives are being investigated. Tests have shown that injection of air as close as possible to the exhaust valves yields the best results. Engine power and fuel economy losses associated with the pump are slight (Ref. 7-7).

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7-3 General Motors Corporation, "Request for Suspension of 1975 Federal Emissions Standards," Volumes I and II, 3 April 1972.

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8. EMISSION GOALS

8.1 GENERAL

In order to comply with the 1975 emission standards on production vehicles at 50,000 miles, the automobile manufacturers must demonstrate substantially lower emission goals on low-mileage engineering prototype vehicles to account for a number of parameters affecting emission control system performance. These parameters include the emission deterioration factor (DF) of the control system, the prototype-to-production slippage factor (PPS), and, in case emission averaging is not permitted, the production quality control factor (QCF). Based on these definitions, the low-mileage emission goals for engineering prototype vehicles are computed from the following equation

$$M_{goal} = \frac{M}{DF \times PPS \times QCF}, \text{ gm/mi}$$

where M represents the 1975 HC, CO, and NO_x emission standards and DF represents the system deterioration factor between low mileage and 50,000 miles. To minimize "green" engine/control-system effects, EPA has selected the 4000-mile point as the low-mileage reference value. It should be noted that deterioration factors must be used with care. In general, deterioration factors determined for one type of vehicle/emission control system are only applicable to similar configurations.

The in-house emission goals established by the various manufacturers for reciprocating spark ignition engine-powered vehicles are presented in Table 8-1. Also listed in this table are the emission goals selected by Toyo Kogyo and Daimler-Benz for rotary engine-powered vehicles. Daimler-Benz

Table 8-1. Low Mileage Emission Goals (Averaging Permitted) Projected 1975 Control Systems

Manufacturer	Emission Control Concept	Emission Goals, gm/mile			Reference Mileage	Selected Control System Deterioration Factor			Prototype-To-Production Slippage Factor	Remarks
		HC	CO	NO_x		HC	CO	NO_x		
I. DOMESTIC										
American Motors	EM + EGR + AI + OC	0.15	2.55	2.2	4000	2.0	–	1.1	≈1.25	Catalyst replacement may be required
	EM + EGR + AI + OC	0.10	1.50	2.2	<10	–	–	1.1	≈1.25	
Chrysler	EM + EGR + AI + PTR + OC	Not specified			–	–	–	–	–	Selection of goals not possible because of unresolved questions (averaging concept, maintenance)
Ford	EM + EGR + AI (+TR) + OC	Not specified			–	–	–	–	–	Uncertainty in system durability characteristics
General Motors	EM + EGR + AI + PTR + OC	0.20	1.7	2.97	–	2.0	2.0	1.5	–	Best estimate of goals; lack of durability data
	Catalyst change at 25,000 miles	0.27	2.27	2.07	–	–	–	1.5	–	
	99.5% of cars meeting standards at 50,000 miles	0.07	0.71	1.16	Low	–	–	–	–	
International Harvester	EM + EGR + AI +(TR) + OC	0.2	1.7	1.5	Low	1.8	1.8	1.8	≈1.1	Estimates for certification vehicles
II. FOREIGN										
British Leyland	EM + AI + OC	0.16	1.36	1.5	Low	2.0	2.0	1.7	1.2	Goals may have to be lowered further
Daimler-Benz	EM + EGR + AI + OC	0.20	2.0	2.0	Low	–	–	–	–	Will meet 1975 emission standards
	Diesel engine (no catalyst)	Not specified			–	–	–	–	–	
	Rotary engine +EGR+AI+OC	0.20	2.0	2.0	Low	–	–	–	–	
Mitsubishi	EM + AI + (TR) + OC	0.14	1.2	1.4	Low	2.0	2.0	–	–	
	EM + AI + TR	0.26	2.2	2.0	Low	–	–	–	–	
Nissan	EM + AI + EGR + OC	0.18	1.50	0.96	Low	2.0	2.0	1.4	1.1	Goals may not be stringent enough (<0.02 gm/gal Pb)
Saab-Scania	EM + AI + OC	0.20	1.7	1.55	Low	2.0	2.0	2.0	–	Preliminary estimate
Toyo Kogyo	EM + AI + OC	0.19	1.5	2.3	Low	2.0	2.0	1.2	1.1	
	EM + AI + TR	0.29	2.3	2.3	Low	1.3	1.3	1.2	1.1	
	Rotary engine + AI + TR	0.29	2.3	2.3	Low	1.3	1.3	1.2	1.1	Toyo Kogyo believes that they can meet these goals
Toyota	EM + AI + EGR + OC	0.19	1.5	1.9	Low	2.0	2.0	1.5	1.1 - 1.2	Preliminary estimates
Volkswagen	EM + (EFI) + AI + EGR + TR + OC	0.17	1.4	0.12*	Low	–	–	–	<1.3	Catalyst replacement at 20,000 mi
Volvo	EM + AI + EGR + OC	0.20	1.7	1.2	Low	–	–	–	–	Preliminary goals; insufficient data

*1976 NO_x GOAL

EFI = Electronic Fuel Injection
EM = Engine Modifications
EGR = Exhaust Gas Recirculation
AI = Secondary Air Injection
TR = Thermal Reactors
OC = Oxidation Catalyst
PTR = Partial Thermal Reactor

has stated that the 220D diesel vehicle will probably meet the 1975 standards but did not provide emission goals for diesels. With the exception of one set of numbers presented by General Motors, the emission goals established by the automobile manufacturers are based on the emission averaging concept (QCF = 1.0). Another set of emission goals presented by General Motors is listed in Table 8-1. This set is based on the assumption that 99.5 percent of the production vehicles meet the 1975 standards at 50,000 miles. This assumption results in such extremely low HC and CO emission levels that it is doubtful whether these values can be attained with current spark ignition engine emission control system technology.

Most manufacturers have assumed HC and CO emission deterioration factors of 2.0 for systems incorporating catalytic converters. Based on the available test data, this assumption appears too optimistic, although further improvements in the carburetion, choke, and ignition systems, and in catalyst performance might be achieved in time for use in 1975 vehicles. Toyo Kogyo has selected a HC and a CO deterioration factor of 1.3 for systems incorporating a thermal reactor only. This is a lower factor than that selected for its systems incorporating a catalytic converter.

NO_x deterioration factors assumed by the manufacturers vary between 1.1 and 1.8. It is believed that these levels are attainable, although EGR system maintenance may be required to accomplish this.

The emission goals presented by the automobile manufacturers are based on the ground rule that catalyst replacement is not permitted during the 50,000-mile test. If catalyst replacement were permitted at intermediate mileage points, the emission goals could be relaxed somewhat. The degree of relaxation is primarily determined by the shape of the emission-versus-mileage curve which is generally different for different vehicle/control system combinations. General Motors is the only manufacturer that has provided emission goals for 25,000-mile catalyst replacement intervals.

8.2 DETERIORATION FACTOR

The deterioration factor (DF) of the emission control system is primarily responsible for the manufacturer's stringent emission goals. This factor accounts for the emission increase which results from the performance degradation with mileage accumulation of all components utilized in the system including the engine, and the catalyst and other aftertreatment devices. In general, the catalytic converter is the critical component. As discussed in Section 5.5, catalyst degradation is the result of poisoning of the active elements by lead, phosphorus, sulfur, and oil additives, and of attrition and exposure to overtemperature conditions. Those manufacturers considering thermal reactor systems expect their deterioration factors to be lower than those of catalyst systems.

Many of the high mileage tests of emission control systems incorporating a catalyst indicate a rather gradual deterioration of emission performance with mileage accumulation. This is illustrated by the HC and CO data provided by American Motors, General Motors, Engelhard, and Ford and by the HC data presented by Matthey Bishop. These data suggest that deterioration factors derived for a particular vehicle/control system are only valid for similar configurations and operating conditions. For example, the deterioration factors derived from a catalyst system operated under idealized conditions (lead-sterile fuel and moderate catalyst temperature) are not necessarily applicable to similar vehicles which are subjected to commercially available "lead-free" fuel and/or more severe durability or customer driving patterns.

Test data provided by Ford from the 1974 California catalyst-only vehicle fleet indicate rapid degradation of the emissions during the first few thousand miles on two of the five vehicles. In both instances the emissions remained essentially constant from this mileage point up to 50,000 miles. This trend is contradictory to other Ford durability data.

The deterioration factors derived from the high mileage emission data provided by the automobile manufacturers are summarized in Figure 8-1. Although it is not possible to precisely correlate these data, it is apparent that the degradation has generally been more severe for systems with low initial (low mileage) emissions.

Since the emission control systems projected for use in 1975 vehicles will incorporate improved carburetion, choke, and ignition systems as well as improved (stabilized) catalytic converters, the emissions and the deterioration factors of these systems should be lower than currently indicated. It appears that this assumption was included in the considerations made by the automobile manufacturers in establishing their deterioration factors.

8.3 PROTOTYPE-TO-PRODUCTION SLIPPAGE FACTOR

The prototype to production slippage factor (PPS) is defined as the ratio of the average emissions of production vehicles compared with the emissions of identical engineering prototype vehicles. Based on past experience, the emissions from production vehicles are, on the average, higher than those of the prototype because of production tolerances and adjustments made in the final design and fabrication of certain components. Although these factors are known for current vehicles, it is difficult to make accurate predictions for future designs. As indicated in Table 8-1, most manufacturers project PPS factors between 1.1 and 1.25.

8.4 PRODUCTION QUALITY CONTROL FACTOR

The production quality control factor (QCF) accounts for the differences between the average emissions of a certain vehicle model and the maximum emissions of a specified percentage of the total vehicle population of that model. The effect of the QCF on the emission goals is illustrated in Figure 8-2, which shows the HC and CO emission distributions from 1971 General Motors production vehicles. Although these curves may not be

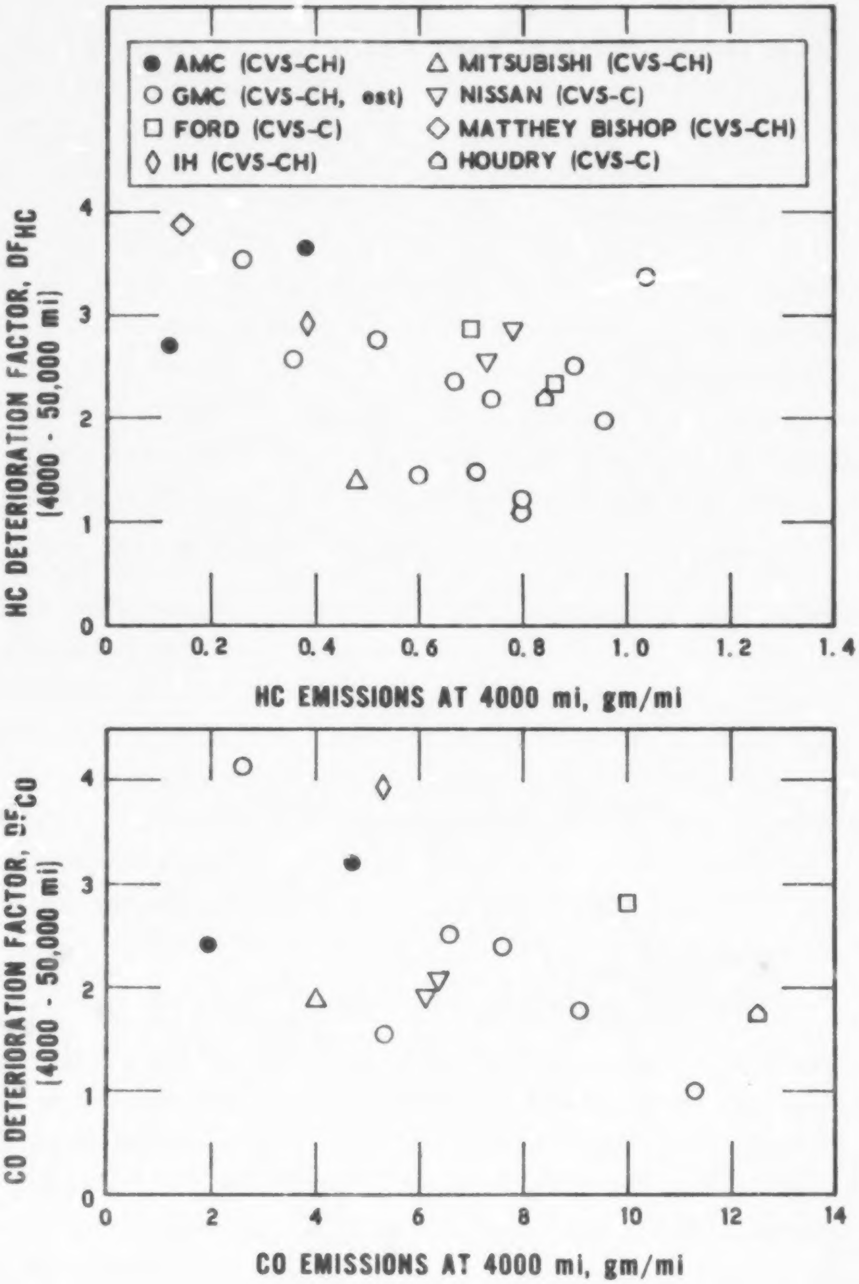


Figure 8-1. Deterioration Factors vs Emissions at 4000 Miles

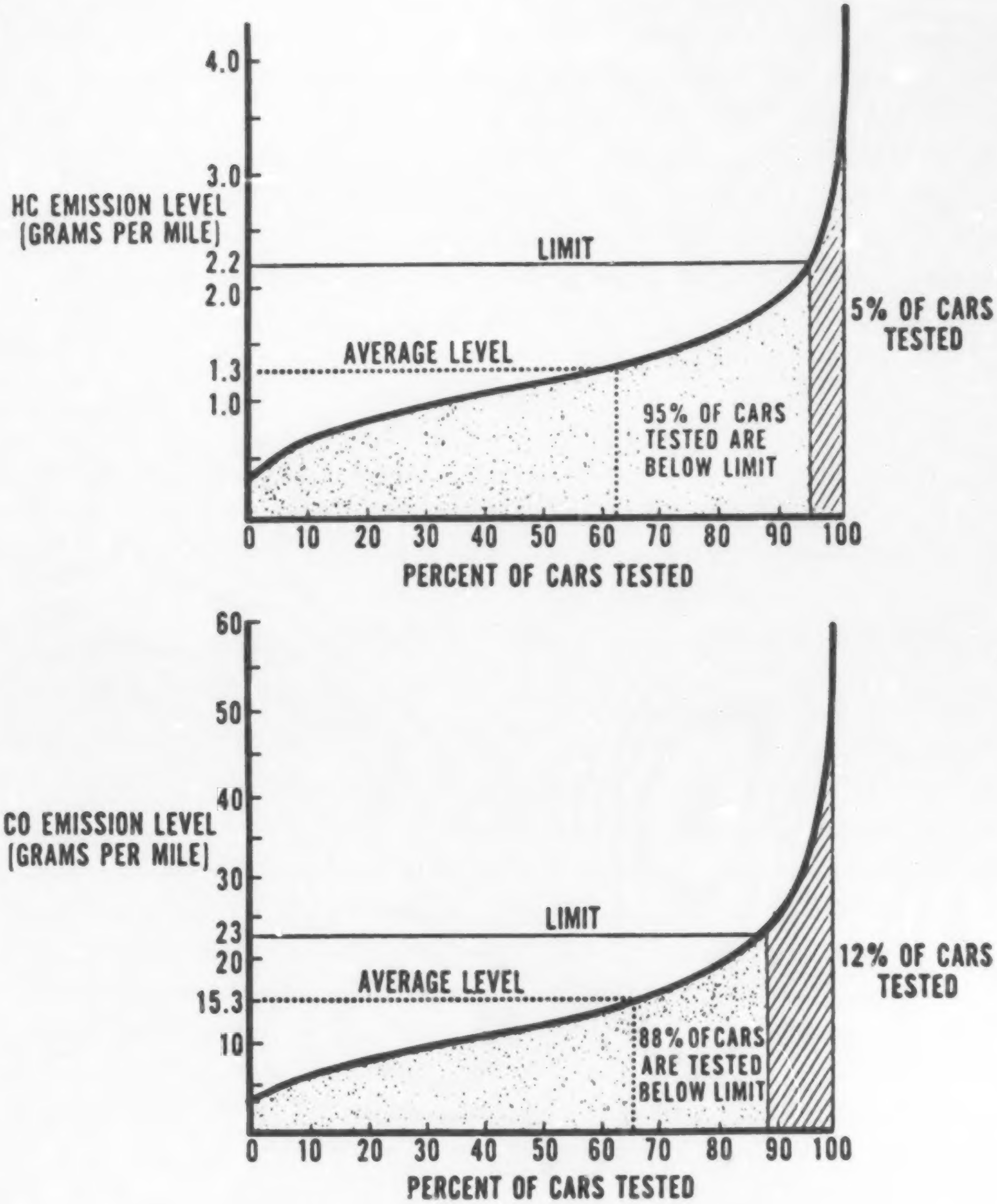


Figure 8-2. HC and CO Emission Levels from 1971 California Car Production Audit (1473 Cars Tested) (GM Production Vehicles)

applicable to 1975 model vehicles, they are presented to show trends. As indicated, extremely low emission goals would be required if a high percentage of the vehicles would have to meet the standards. For example, QCF's of approximately 2.8 for HC and 3.1 for CO would be required to achieve compliance with 99.5 percent of General Motors vehicles in Figure 8.2. This results in correspondly tighter emission goals. Conversely, if the emission averaging concept is adopted, the QCF has no effect on the emission goals (QCF = 1.0).

8.5 SELECTED PROTOTYPE EMISSION GOALS

8.5.1 American Motors

The following prototype emission goals have been established by American Motors for its 1975 first-choice system, which consists of engine modifications, oxidation catalysts, and EGR (Ref. 8-1).

Reference Mileage	1975 CVS-CH Emissions, gm/mi		
	HC	CO	NO_x
4000	0.15	1.35	2.2
Less than 10	0.1	--	2.2

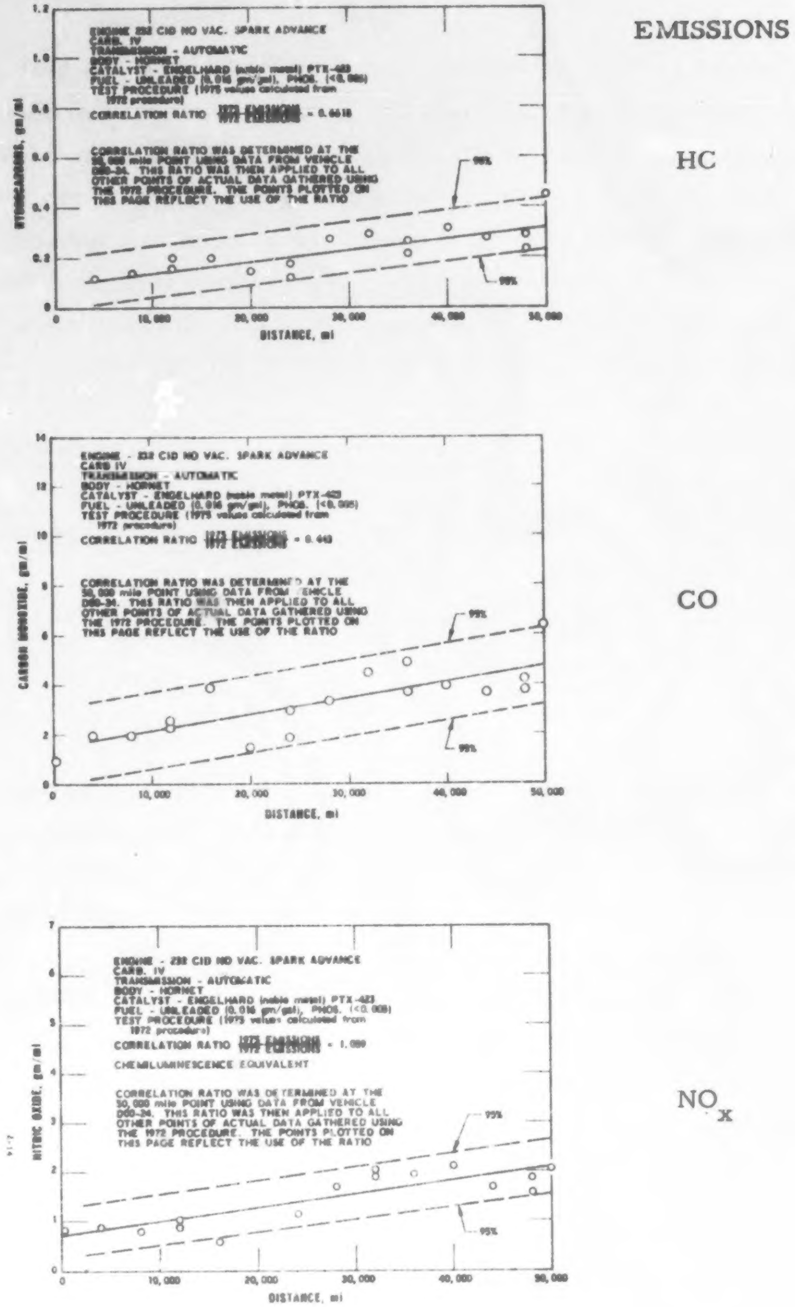
These numbers are based on the use of 4000-mile to 50,000-mile emission deterioration factors of 2.0 for HC and CO and 1.1 for NO_x, and a prototype-to-production slippage factor of 1.25. Since the HC and CO deterioration factors demonstrated by American Motors to date are significantly higher, catalyst replacement may be required during the 50,000-mile period. American Motors forsees no difficulty in meeting the NO_x standard over the 50,000-mile range without EGR maintenance. Substantially lower HC and CO emission goals were selected for "zero mileage" vehicles to account for "green system" effects.

Emission control system durability data from two American Motors Hornet vehicles (Vehicles DOO-24 and DOO-25) equipped with an Engelhard PTX-423 catalyst and operated on fuel containing 0.016 gm/gal lead and less than 0.005 gm/gal phosphorus are presented in Figures 8-3 through 8-8. As indicated in these figures, the emission deterioration is approximately linear with mileage accumulation. The deterioration factors derived from these data are shown below. For Vehicle DOO-25, the factors are based on a linear extrapolation of the data from 24,000 to 50,000 miles.

	Vehicle DOO-24		Vehicle DOO-25	
DF	Miles 0-4000	Miles 4000-50,000	Miles 0-4000	Miles 4000-50,000
HC	-	2.72	-	3.66
CO	1.95	2.41	1.27	3.20
NO_x	1.13	2.38	1.0	1.00

The HC and NO_x emissions of Vehicle DOO-24 were within the standard at 50,000 miles, while the CO standard was exceeded at approximately 30,000 miles. As indicated by Engelhard (Ref. 8-2), the CO emissions on that vehicle should be reduced with use of a 1975-type advanced carburetor. Although the 4000-50,000 mile deterioration factors for HC and CO Vehicle DOO-25 are only slightly higher than those of Vehicle DOO-24, the standards are exceeded at very low mileage. This illustrates that the system specific deterioration factor must be coupled with the system specific low mileage emissions when projecting emission control system performance to high mileage.

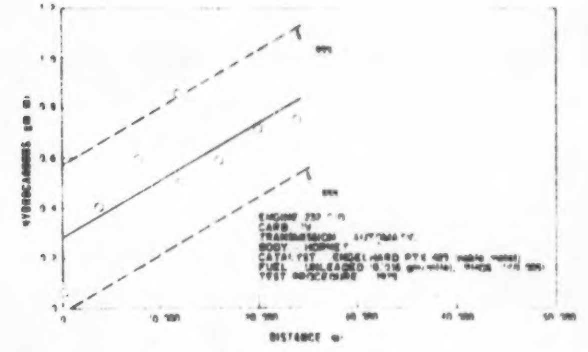
The lead and phosphorus levels of the fuel used in these tests were of the order of 50 percent of those allowed by the proposed EPA fuel additive regulations. Since fuel contaminants affect catalyst durability, the emission deterioration factors computed from the American Motors data may be



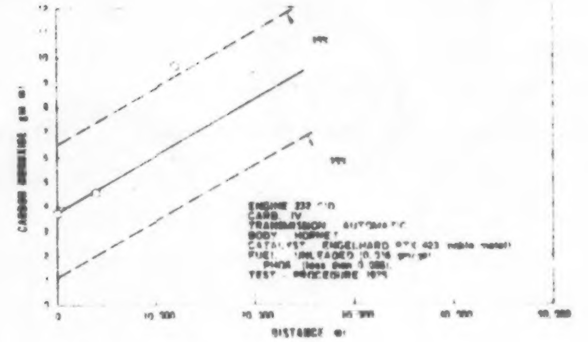
Figures 8-3, 8-4, 8-5. American Motors Durability Test Data--Vehicle D00-24

EMISSIONS

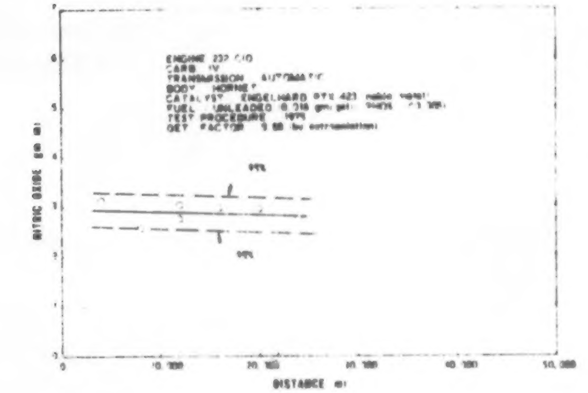
HC



CO



NO_x



Figures 8-6, 8-7, 8-8. American Motors Durability Test Data--Vehicle D00-25

optimistic. Conversely, incorporation of "second-generation" improved catalysts may actually result in a reduction of the deterioration factors. At this time there is insufficient information available for a meaningful assessment of these parameters.

It should be noted that Vehicle DOO-24 was tested in accordance with the 1972 Federal test procedure. The data was then adjusted by American Motors by a factor which was determined from 1972 and 1975 test procedure data taken at the 50,000-mile point. This approach is considered an approximation only.

The emission goals selected by American Motors include a factor of 1.25 to account for prototype-to-production slippage. Although current test data indicate slippage factors of 1.3 to 1.35, American Motors expects by 1975 to approach the value of 1.25 through use of improved production, inspection, and calibration procedures. Test-to-test variability considerations were neglected and the concept of emission averaging was assumed for new vehicles and for vehicles in the field.

8.5.2 Chrysler

The engineering goal of the Chrysler Corporation for 1975 emission control is to develop a system which will achieve the emission standards through 50,000 miles of normal operation while at the same time exhibit safe, acceptable driving characteristics. Chrysler recognizes that emission control systems suffer deterioration as mileage is accumulated. In past model years, the emission deterioration at 50,000 miles has been of the order of 33 percent (Ref. 8-3). However, these factors are not applicable to 1975-type emission control systems utilizing catalysts with currently unknown durability and deterioration characteristics.

Chrysler states that several questions have to be answered by EPA before meaningful emission goals can be established which will ensure that mass-produced vehicles will meet the 1975 emission standards for their useful life. These questions are related to emission averaging procedures, vehicle/ emission control system maintenance, and assembly line testing (Ref. 8-3). In addition, catalyst operating temperature and fuel contaminant levels, including lead, sulfur, and phosphorus, affect emission control system durability to a degree that cannot be determined by Chrysler at this time (Ref. 8-4).

Chrysler provided high mileage emission test data from Cars 333 and 698. Both vehicles incorporated Engelhard PTX catalysts, and were operated with fuel containing 0.02-0.03 gm/gal lead. Car 333 was operated under controlled conditions, with the maximum catalyst temperature limited to 1500 °F. Frequent tuneups were made for the purpose of establishing the potential of catalytic control systems under "mild" operating conditions. Since higher catalyst temperatures may be reached in customer vehicles, this test is not considered representative by Chrysler with respect to the performance and safety characteristics of its projected 1975 control system.

The HC and CO emissions from Car 333 (1972 CVS-C procedure) are presented in Figures 8-9 and 8-10. As indicated, the data are rather erratic but the emissions are encouraging and the average deterioration factors are low. Similar results were obtained from Car 698.

8.5.3 Ford Motor Company

In their application for suspension (Ref. 8-5), Ford states that current uncertainty in the deterioration factors of 1975-type vehicles precludes at this time the establishment of meaningful emission goals. Initially, Ford's engineering objectives for its principal ("kitchen sink") 1975 control system were based on the optimistic belief that the average emission levels would increase by no more than 100 percent for HC and CO and 40 percent for NO_x, from zero to 50,000 miles (Ref. 8-5). In addition, Ford assumed a factor of 1.1 to account for production slippage between development and certification vehicles. Although based on very preliminary projections rather than actual

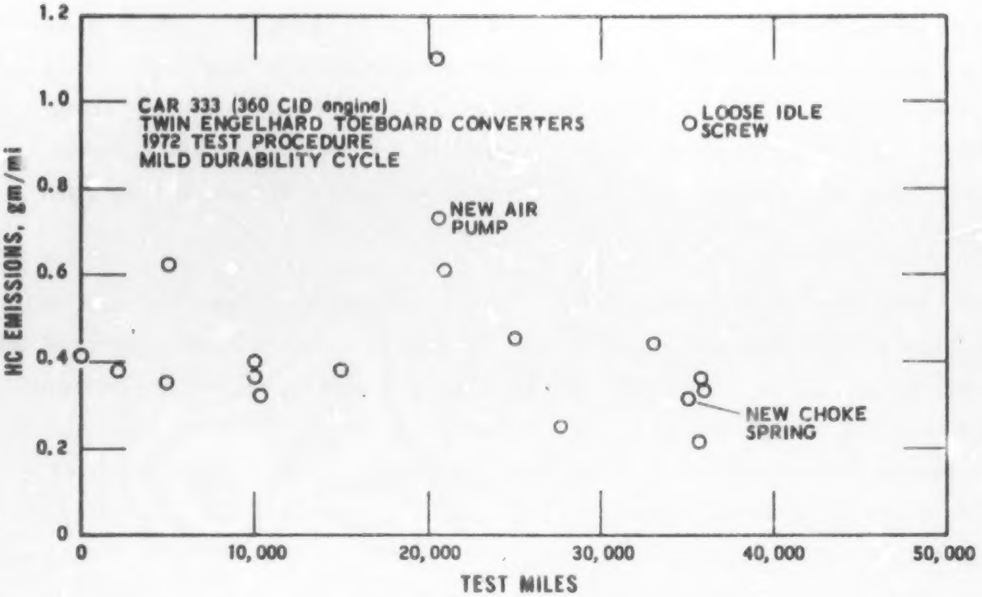


Figure 8-9. Chrysler Durability Test Data (HC Emissions)

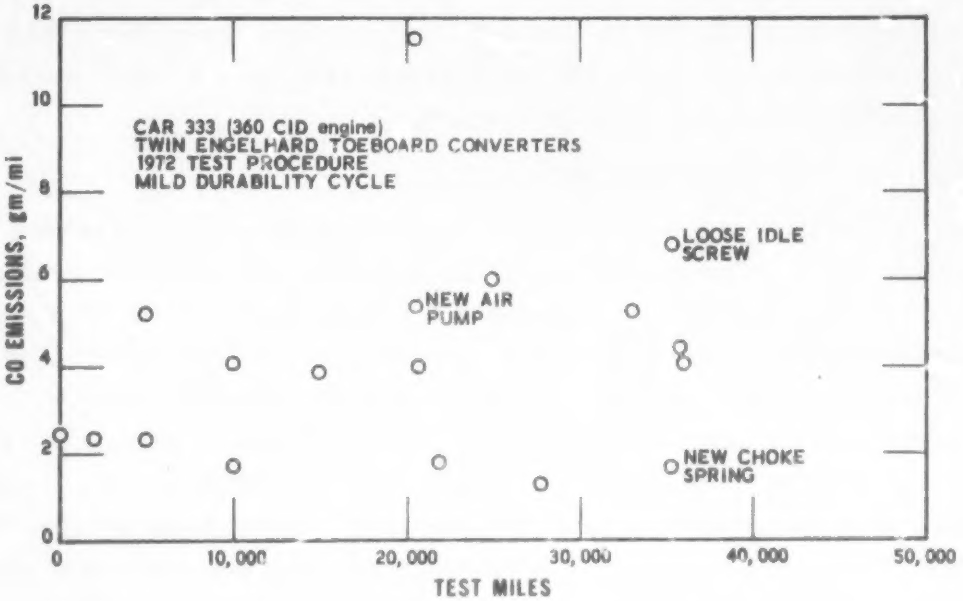


Figure 8-10. Chrysler Durability Test Data (CO Emissions)

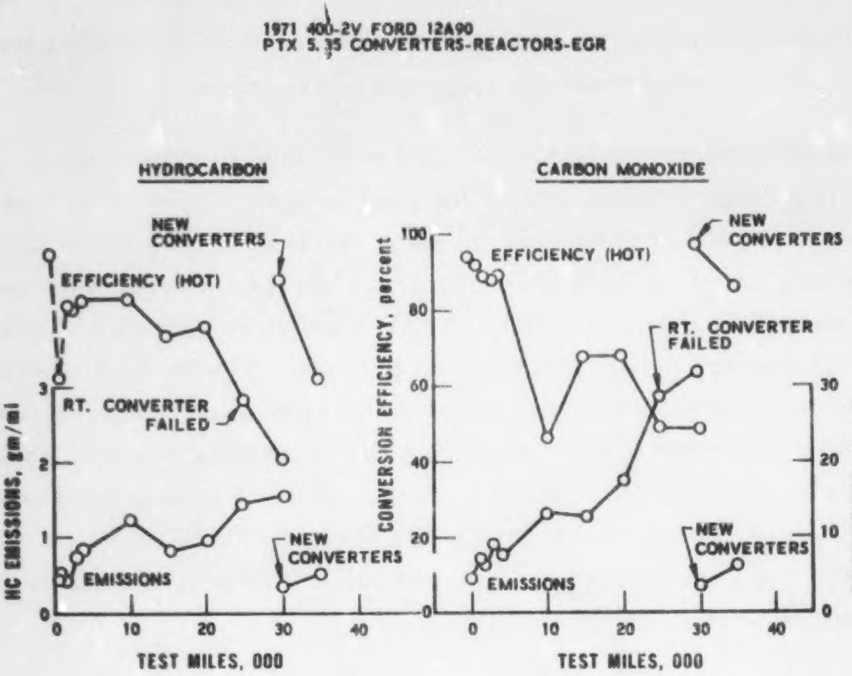
test experience with the 1975 system, these objectives provided an initial target for Ford's development and engineering programs.

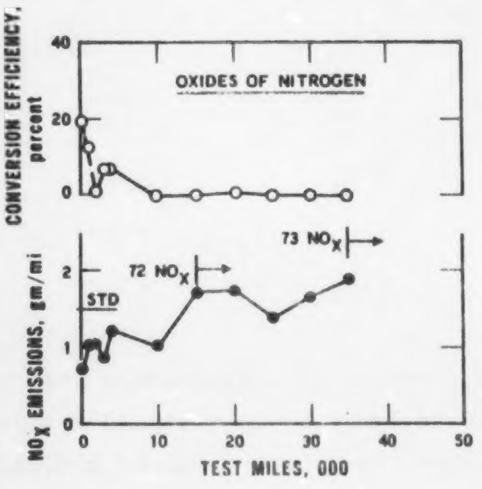
Based on further experimental work on six combined thermal reactor/catalyst vehicles, the average emission deterioration factors projected by Ford for these systems are 2.2 for HC, 1.8 for CO, and 1.1 for NO_x between zero and 4000 miles, and 1.8, 2.0, and 1.3, respectively, between 4000 and 50,000 miles. The emission data from two of these vehicles are presented in Figs. 8-11 through 8-14. Considering test data variabilities, there seems little justification for using different deterioration rates for the low and high mileage regimes. The data from the remaining vehicles show similar trends. In all cases the 1975 HC and CO standards were exceeded at low mileage. The NO_x emissions were always below the 1975 standard. Ford attributes the rapid performance deterioration to component failures and maladjustments, as well as catalyst degradation.

Deterioration factors derived from these data by linear extrapolation are as follows:

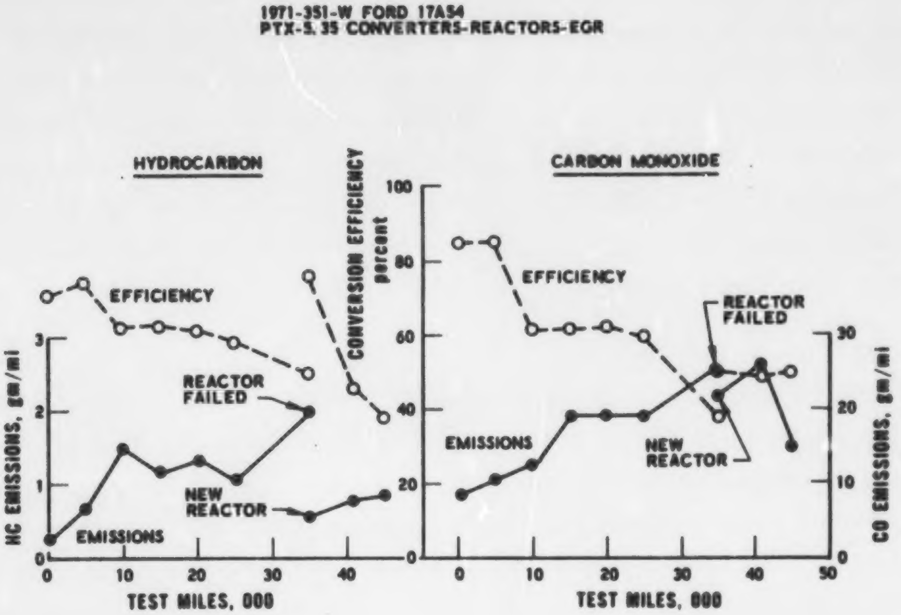
	Vehicle 12 A 90		Vehicle 17 A 54	
DF	Miles 0-4000	Miles 4000-50,000	Miles 0-4000	Miles 4000-50,000
HC	2.1	2.21	2.41	2.86
CO	1.69	4.9	1.20	2.80
NO_x	1.57	2.28	1.28	1.55

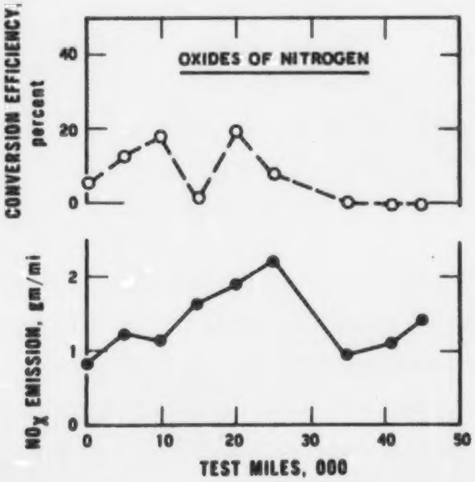
Additional high mileage test data were provided by Ford from the 1974 California catalyst-only vehicle fleet which was designed to meet the less stringent 1974 California emission standards. As discussed in Section 9, the deterioration factors derived from these data were used to establish the interim





Figures 8-11, 8-12. Ford AMA Durability Test Data (1975 System)





Figures 8-13, 8-14. Ford AMA Durability Test Data standards proposed by Ford for 1975. The HC and CO emissions from two of these vehicles are presented in Figures 8-15 and 8-16. As indicated in Figure 8-15, the HC and CO emissions increase very rapidly during the first 2000 miles and remain essentially constant to 50,000 miles. Data from three other vehicles in this fleet show similar trends. However, on one of these three vehicles only 7-mode data were provided by Ford for the low mileage region and leaded fuel was used on one of these vehicles between 12,000 and 14,000 miles. Conversely, the data in Fig. 8-16 show a more gradual degradation.

Ford is in the process of developing additional data from several potential emission control systems. Although low mileage data from the Ford Riverside test program indicate a reduced rate of deterioration for the first 4000 miles, Ford is not revising its emission goals on the basis of this preliminary information. The average zero-to-4000-mile HC, CO, and NO_x deterioration factors of the Riverside Group I vehicles are 1.18, 1.45, and 1.14, respectively. Over the same interval, the average catalyst deterioration factors are 1.67 for HC and 1.25 for CO, indicating "green engine" effects and/or measurement variabilities. These values are considerably lower than those from the catalyst-only and thermal reactor/catalyst vehicle fleets discussed above, and Ford is very encouraged by these results. Similar results were obtained from the Group II and Group III vehicles. The average zero to 4000-mile deterioration factors computed from the Dearborn fleet are comparable to the Riverside fleet data, although the CO levels are generally higher and the NO_x levels somewhat lower for the Dearborn fleet.

Another important subject related to establishing emission goals is the ability to accurately measure emissions at the low 1975 levels. Although considerable progress has been made in the past few years, a number of testing problems remain unresolved which have a significant impact upon, selection of and compliance with realistic emission goals. These problems concern data variability, correlation, instrumentation, and vehicle operation.

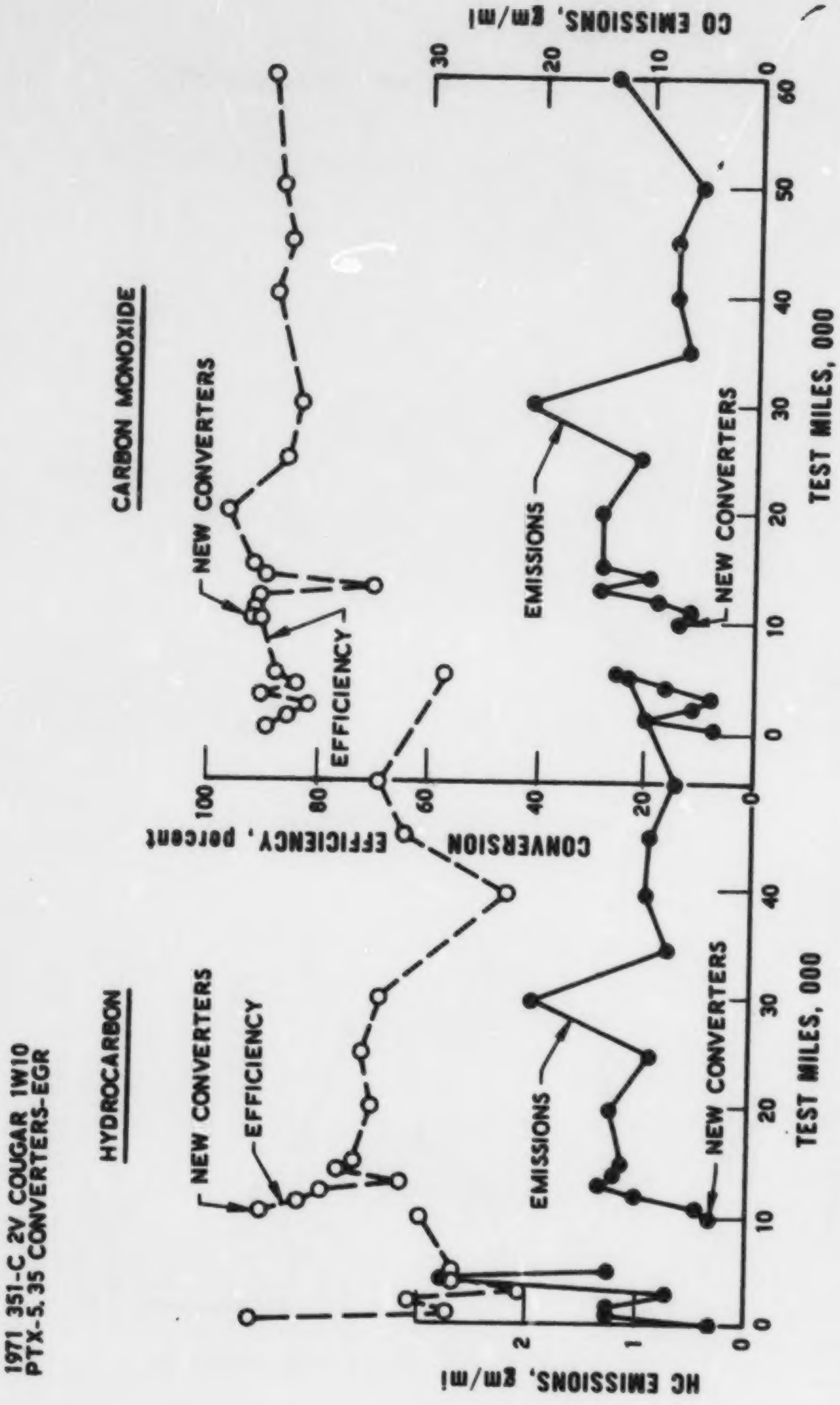


Figure 8-15. Ford AMA Durability Test Data

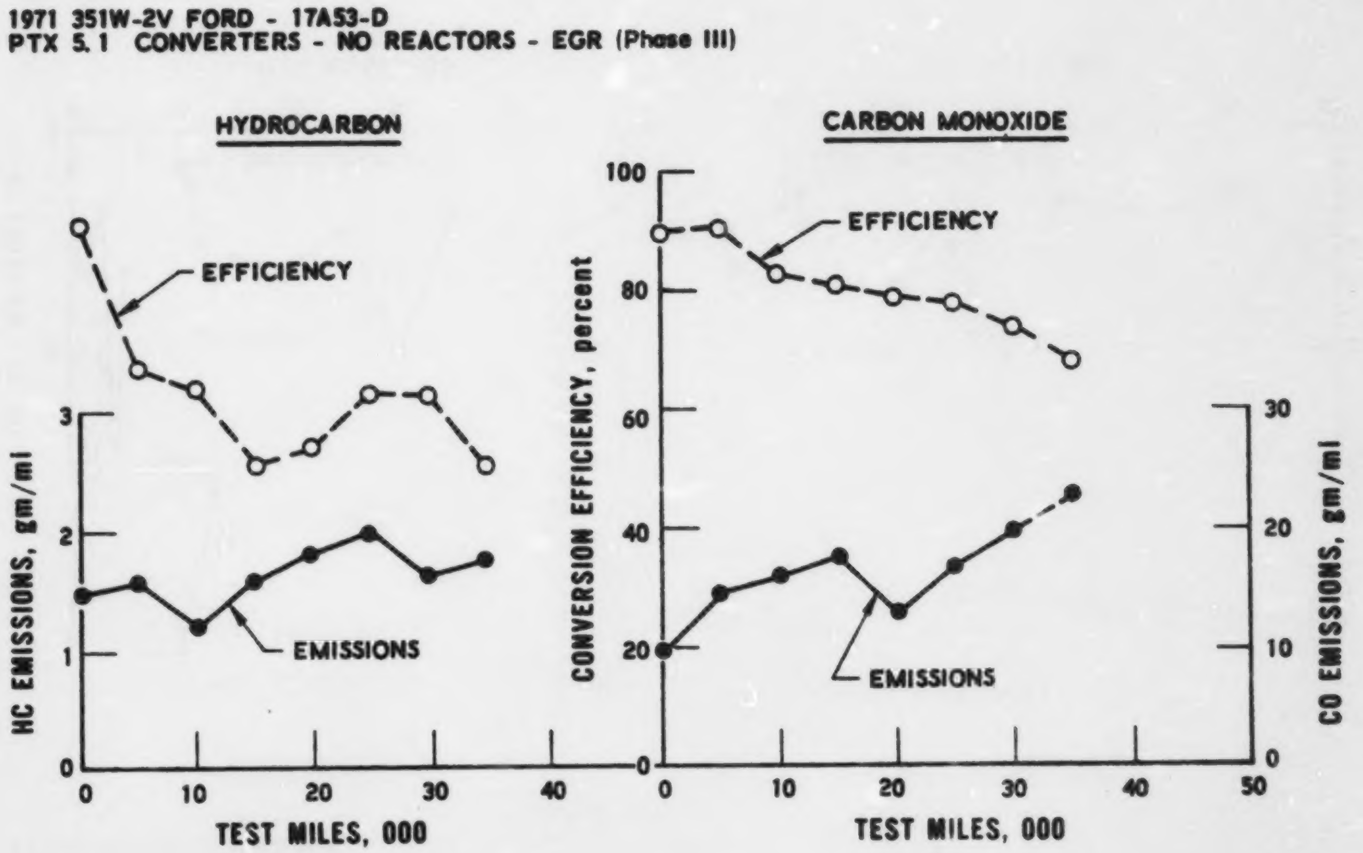


Figure 8-16. Ford AMA Durability Test Data

The effect of these emission testing-related problems on the emission goals is illustrated in the following table:

	HC	CO	NO_x
Standard - gm/mi	0.41	3.4	0.4
Typical Allowance for Variability - %	42.7	55.9	37.8
Correlation Allowance - %	15.0	15.0	15.0
Total Uncertainty in %	57.7	70.9	52.8
Total Uncertainty in gm/mi	0.24	2.4	0.21
Required Objective*	0.17	1.0	0.19

---

*Does not include system deterioration

The net effect is the equivalent of a 50-to-70-percent reduction in the 1975 emission standards due to emissions testing variabilities. By comparison, as discussed in Section 9, Ford used a factor of only 1.2 in computing its proposed interim standards. Ford believes that this factor can be achieved through improvements in test equipment, instrumentation, testing techniques, and emission averaging.

8.5.4 General Motors

General Motors states that it currently is not in a position to establish accurate engineering emission goals for 1975 model vehicles because of a lack of reliable control system deterioration factors and uncertainty whether emissions averaging and/or catalyst change at intermediate mileage points will be allowed by EPA. In addition, it feels that the questions of fuel contaminant levels, and vehicle recall and warranty must be fully resolved (Ref. 8-6).

At the request of the EPA Suspension Hearing Panel, General Motors has provided AMA durability test data from two vehicles operated with base metal catalytic converters for more than 30,000 miles and tested in accordance with the 1975 test procedure. These data, which are presented in Figures 8-17 through 8-19, indicate almost linear HC and CO emission deterioration with mileage accumulation and somewhat erratic NO_x emission distributions. Also presented in these figures are test data from Car 61319, utilizing an Engelhard PTX-4 catalyst. Although the emissions appear to level off on Car 61319 after 5000 to 10,000 miles, the data sample is inadequate to draw meaningful conclusions with respect to emission deterioration.

The following deterioration factors were established from Figures 8-17 to 8-19:

	Car 933		Car 2233	
DF	Miles 0-4000	Miles 4000-50,000	Miles 0-4000	Miles 4000-50,000
HC	1.3	3.54	1.16	2.56
CO	1.45	4.11	1.18	2.50
NO_x	1.00	0.96*	-*	-*

---

*very erratic data

As indicated, the 4000- to 50,000-mile deterioration factors of Car 2233 are significantly lower than those of Car 933, but the emissions on that car are higher. This illustrates again that the deterioration factor alone is not a meaningful criterion for evaluating performance of emission control systems.

High mileage data from vehicles operated at constant speed (50 mph) were provided by the AC Spark Plug Division of General Motors. The data from two of these vehicles are depicted in Figures 8-20 and 8-21 (1975 CVS-CH test procedure). Again, the emissions increase approximately linearly as mileage is

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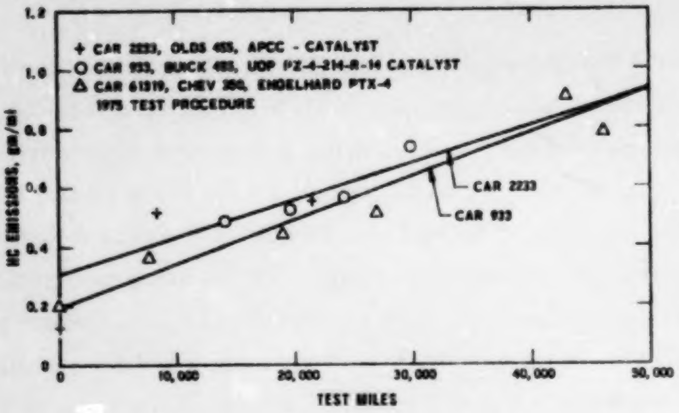
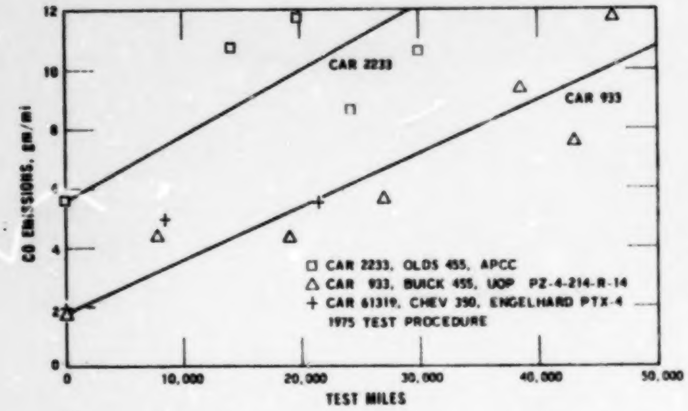
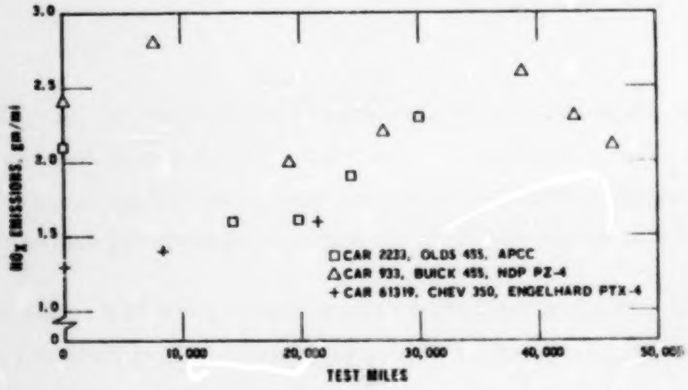


HC



CO



NO_x

Figures 8-17, 8-18, 8-19. General Motors Test Data

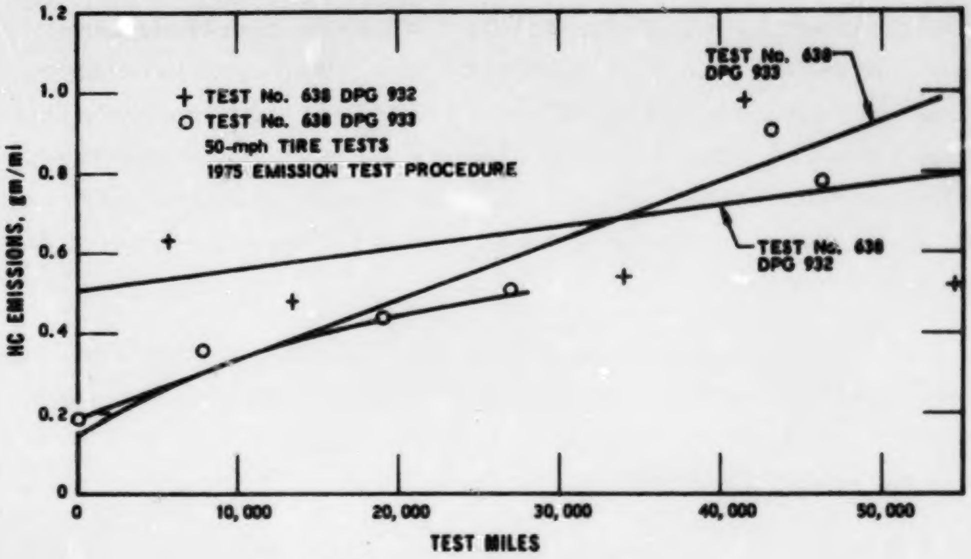


Figure 8-20. General Motors (AC Division) Durability Test Data (HC Emissions)

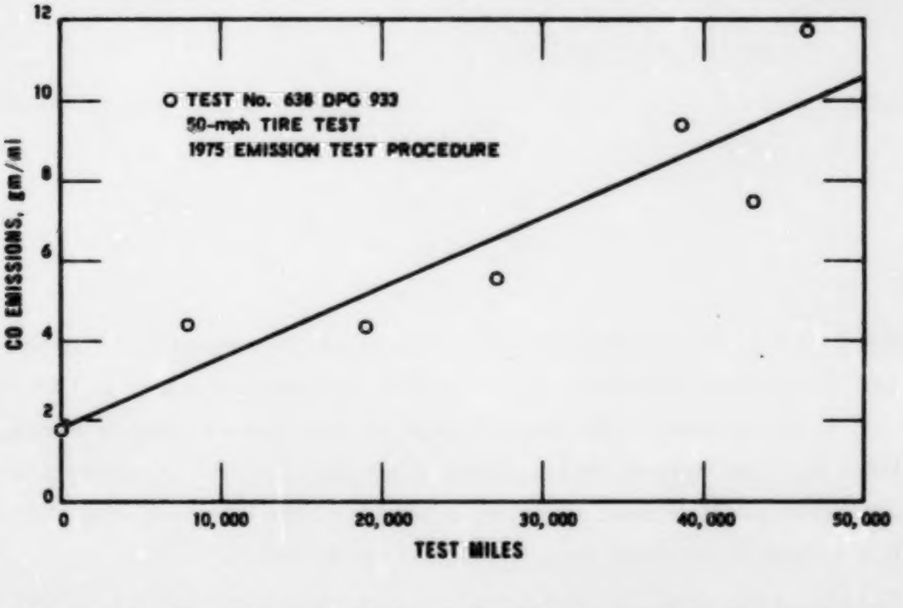


Figure 8-21. General Motors (AC Division) Durability Test Data (CO Emissions)

accumulated, except for CO on Car 638 DPG 932 which decreases from 18.4 gm/mi at zero mile to 4.73 at 50,000 miles. While this CO change phenomenon was not explained by AC it may have resulted from faulty choke operation. Since these data are from constant-speed tests, no efforts were made to derive deterioration factors. The data are presented primarily to illustrate that substantial system deterioration can occur even under mild operating conditions.

The high mileage data from AC Spark Plug Test 472 are not considered here because of uncertainties with respect to the test procedure. According to General Motors (Ref. 8-7), these data are based on the 7-mode test procedure, but this is not evident from the test log sheet.

As requested by the EPA Suspension Request Hearing Panel, General Motors has provided emission data at 4000 miles and 50,000 miles from 11 additional vehicles equipped with either noble or base metal bulk catalysts (Ref. 8-8). Many of these vehicles have high emissions initially (under 4000 miles). The deterioration factors computed from those data are included in Fig. 8-1.

8.5.5 International Harvester

The emission goals (in grams per mile) established by International Harvester for low mileage certification vehicles using catalysts are:

HC = 0.2
CO = 1.7
NO_x = 1.5

These values are based on assumed deterioration factors of 1.2 for the engines and 1.5 for the catalyst, and a factor of approximately 1.1 to account for production variations, with the assumption that the averaging concept will be permitted for production vehicle emissions (Ref. 8-9). Furthermore, periodic catalyst replacement is being considered by International Harvester to meet the selected catalyst deterioration factor of 1.5.

International Harvester has provided limited AMA durability data from Travelall vehicles equipped with base metal catalysts and operated on commercially available "unleaded" fuel. In all cases, the emissions at low mileage were approaching or exceeding the 1975 standards. The data from Vehicle 2, which was tested in accordance with the 1975 test procedure, are shown in Figure 8-22. The emission deterioration on this vehicle is approximately linear with mileage. If these data are extrapolated, the following deterioration factors are obtained:

DF	Miles 0-4000	Miles 4000-50,000
HC	1.18	2.90
CO	1.35	3.93
NO_x	Excessive data scatter	

8.5.6 British Leyland

The 1972 emission goals (in grams per mile) for low mileage engineering prototypes are:

HC = 0.16
CO = 1.36
NO_x = 1.50

These values are based on an assumed system deterioration factor of 2.0, a 20-percent allowance to account for production variations, and on the assumption that emission averaging will be allowed for production vehicles (Ref. 8-10). However, test data provided by British Leyland indicate that the emission deterioration of current systems is significantly higher. For example, the HC and CO emissions obtained from an Austin Marina vehicle

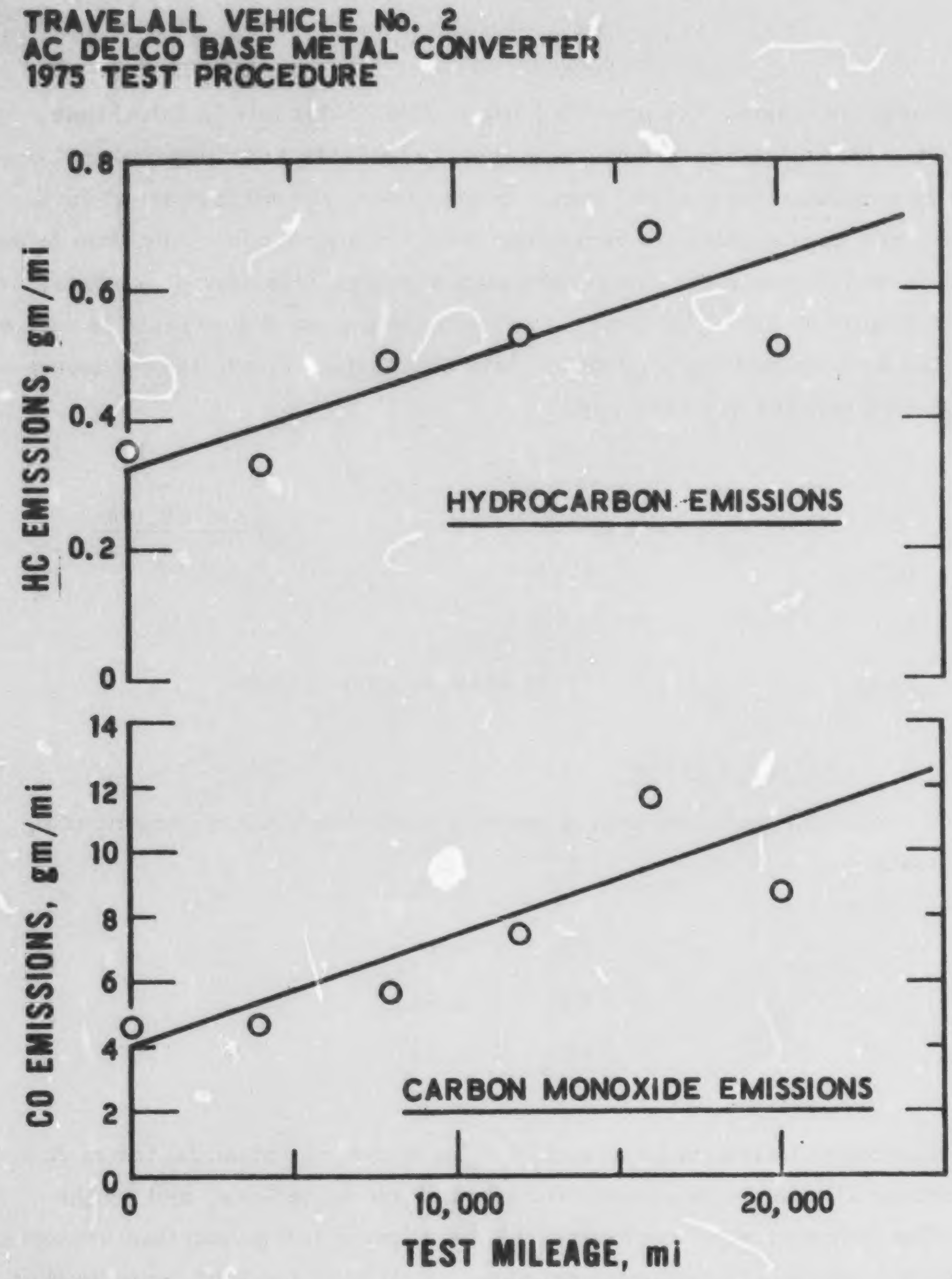


Figure 8-22. International Harvester Emission Data

equipped with an Engelhard stacked PTX catalyst are 0.11 gm/mi and 1.78 gm/mi, respectively, at zero mile, and 0.63 gm/mi and 4.65 gm/mi at 17,000 miles. The NO_x emissions decreased during that period from 1.86 gm/mi to 1.32 gm/mi. Although the data sample is too limited to draw firm conclusions, the HC and CO emission deterioration in the range tested increases gradually with mileage accumulation. In the past the prototype-to-production slippage factor on British Leyland vehicles has varied between 1.0 and 1.25. However, these slippage factors may not be applicable to the catalytic systems projected for use in 1975.

8.5.7 Daimler-Benz

The low mileage prototype emission goals (in grams per mile) established by Daimler-Benz for both reciprocating and rotary spark ignition engines are:

HC = 0.20

CO = 2.0

NO_x = 2.0

These values include assumed allowances for catalyst deterioration, prototype-to-production slippage, and measurement inaccuracies (Ref. 8-11). Considering the test data presented by Daimler-Benz, these goals appear rather optimistic.

Low mileage goals for diesel-powered vehicles were not specified. However, according to Daimler-Benz the 220D vehicles will probably meet the 1975 standards for HC, CO, and NO_x.

8.5.8 Mitsubishi

Although the extent of additional catalyst improvements cannot be predicted by Mitsubishi at this time, it considers the following emission goals (in grams per mile) to be reasonable estimates for 1975 catalytic and thermal reactor systems (Ref. 8-12).

	Catalyst	Thermal Reactor
HC	0.14	0.26
CO	1.2	2.2
NO_x	1.4	2.0

The values for the catalyst system are based on assumed HC and CO deterioration factors of 2.0 and a production quality control factor of 1.5 to account for production variations. If emissions averaging is permitted, the QCF factor becomes unity and the emission goals will be relaxed accordingly.

Based on data provided by Mitsubishi from an unidentified vehicle tested with an Engelhard PTX-5 catalyst and unleaded fuel, the following deterioration factors were derived.

DF	Miles 0-4000	Miles 4000-50,000
HC	1.60	1.37
CO	1.33	1.88

NO_x data were not presented by Mitsubishi. Over the range of data shown (zero to 29,000 miles), CO emissions increase gradually with mileage while HC increases rapidly in the first 2000 miles and very slowly thereafter. More rapid emission degradation was observed with a pelletized catalyst. In all cases, the emission standards were exceeded at very low mileage.

8.5.9 Nissan

In an effort to meet the 1975 emission standards, Nissan has established the following emission goals (in grams per mile) for engineering prototype vehicles (Ref. 8-13).

HC = 0.18

CO = 1.50

NO_x = 0.96

These goals are based on unleaded gasoline (less than 0.02 gm/gal Pb) and utilization of the emission averaging concept. The selected NO_x goal is sufficiently low to satisfy both the 1975 Federal and proposed California emission standards.

Deterioration factors of 2.0 for HC and CO and 1.4 for NO_x were assumed, and a prototype-to-production slippage factor of 1.1 was used for all pollutants. The slippage factor was derived from 1971 and 1972 model year data. Deterioration factors derived from Nissan 1971 and 1972 certification vehicles are approximately 1.15 for HC and CO and 1.0 for NO_x. Although these factors are not directly applicable to 1975 vehicles, they provide an indication of the engine contribution to the deterioration over 50,000 miles.

As illustrated in Figure 8-23, the data obtained by Nissan indicate substantially higher HC emission degradation. The following deterioration factors are obtained by linear extrapolation of these data:

	Vehicle B-263		Vehicle B-415	
DF	Miles 0-4000	Miles 4000-50,000	Miles 0-4000	Miles 4000-50,000
HC	1.18	2.85	1.82	2.53
CO	1.09	1.90	1.10	2.08

8.5.10 Saab

In preparing for the 1975 Federal emission standards, Saab-Scania has established emission goals for low mileage prototype vehicles of 50 percent or less of the 1975 standards. These goals were selected on the basis of

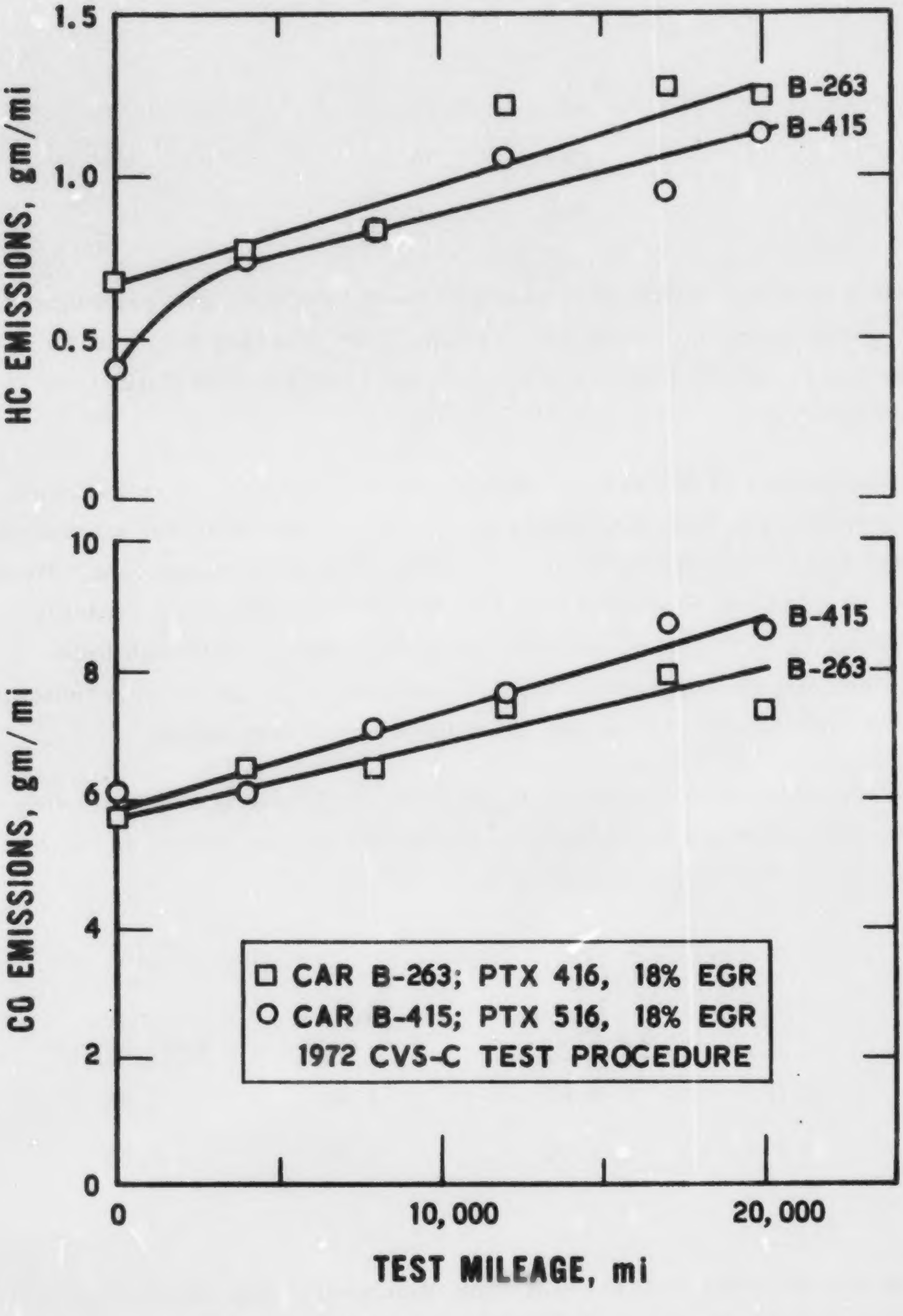


Figure 8-23. Nissan Durability Test Data

information extracted from the open literature and from extrapolation of Saab test data. Since the durability data provided by Saab is limited to less than 11,000 miles, derivation of meaningful deterioration factors is not possible at this time (Ref. 8-14).

Prototype-to-production slippage factors for the 1975 systems are currently not known. It is expected that this factor will be lower for catalyst systems than for thermal reactor configurations which are generally more sensitive to air/fuel ratio variations. Also, application of fuel injection systems is expected to result in lower slippage factors compared with vehicles using carburetors.

8.5.11 Toyo Kogyo

In order to meet the 1975 Federal emission standards, Toyo Kogyo has established the following emission goals (in grams per mile) for rotary and reciprocating spark ignition engines (Ref. 8-15):

System	HC	CO	NO_x
Rotary Engine, Thermal Reactor	0.29	2.3	2.3
Reciprocating Engine, Thermal Reactor	0.29	2.3	2.3
Reciprocating Engine, Oxidation Catalyst	0.19	1.5	2.3
Reciprocating Engine, Thermal Reactor + Oxidation Catalyst	0.19	1.5	2.3

The emission goals of the thermal reactor systems were established on the basis of a 50,000-mile prototype-to-production slippage factor of 1.1, HC and CO deterioration factors of 1.3 each, and a NO_x deterioration factor of 1.2. The selected deterioration factor for HC and CO is based on the experience gained on 1970-72 model year rotary engine vehicles using a thermal reactor.

Lower goals were set for the catalyst systems, primarily because of a lack of sufficient test data and experience with this type of system. The IIEC targets were used as a guideline in setting the goals.

8.5.12 Toyota

Toyota has tentatively selected the following low-mileage emission goals (in grams per mile) (Ref. 8-16).

HC = 0.19

CO = 1.5

NO_x = 1.9

These goals were established by assuming emission averaging and performance deterioration over the life of the system. In addition, a prototype-to-production slippage factor of 1.1 to 1.2 was assumed. Although it has been difficult for Toyota to predict accurately the deterioration rate of oxidation catalysts over 50,000 miles, factors as high as 3.0 for HC and 2.5 for CO are indicated from Toyota bench test data for 25,000 miles, using fuel with a lead level of 0.01 to 0.02 gm/gal. Toyota is optimistic with respect to future reduction of these factors by means of improved catalysts. The NO_x deterioration factor is estimated to be approximately 1.5.

8.5.13 Volkswagen

As stated by Volkswagen (Ref. 8-17), the following emission goals (in grams per mile) have been selected for 1975 prototype vehicles:

HC = 0.17

CO = 1.4

NO_x = 0.12

The NO_x goal was established on the basis of utilizing a reduction catalyst as part of the Volkswagen emission control system which is being developed to meet both the 1975 and 1976 emission standards. Although the reduction catalyst will not be used on 1975 model vehicles (Ref. 8-18), NO_x emission goals were not provided by Volkswagen for their 1975 system.

The emission goals are based on catalyst replacement at 20,000-mile intervals and include an allowance for catalyst deterioration and laboratory test variabilities. Prototype-to-production slippage was not taken into account because of a lack of applicable production experience on systems of this type (Ref. 8-18).

Volkswagen states that accurate prediction of system deterioration is currently not possible. However, recent test data indicate that the catalyst reactivity decreases in 20,000 miles by approximately 40 percent for HC and CO and 55 percent for NO_x.

8.5.14 Volvo

Since first-choice system durability data are currently not available, Volvo has established the following emission goals (in grams per mile) on the basis of very limited catalyst bench and vehicle test data (Ref. 8-19):

HC = 0.2
CO = 1.7
NO_x = 1.2

These goals will be adjusted as more data become available from the 1975 emission control system test program. Data from one vehicle utilizing an Engelhard PTX-416 catalyst indicate low HC and CO emissions and deterioration factors. However, catalyst failure occurred at 29,900 miles.

8.5.15 Catalyst Manufacturers

None of the catalyst manufacturers has established emission goals for 1975 vehicle/control systems. However, a number of these manufacturers have provided encouraging emission durability data from a number of test vehicles. The highlights from these programs are briefly discussed here.

The Houdry Division of Air Products has provided AMA durability data from an early base metal catalyst which was tested in accordance with the 1972 CVS-C test procedure (Ref. 8-20). The emission data from this test are depicted in Figure 8-24. As indicated in the figure, the emissions increase approximately linearly with mileage. The average 4000- to 50,000-mile deterioration factors are 2.19 for HC and 1.77 for CO. The 1975 standards are exceeded at zero mileage.

Engelhard has provided high mileage emission data from a vehicle equipped with a PTX-5 catalyst and driven over a city suburban route. The test data, which are included in Section 5.7.4, indicate very low HC and CO emissions and deterioration factors. Although the vehicle has not completed 50,000 miles and was not tested on the AMA cycle, the data are encouraging.

Data from New York police cars equipped with PTX-5 catalysts were also provided by Engelhard (Ref. 8-21). The catalyst conversion efficiencies computed from these data are presented in Figure 8-25. The HC conversion efficiency decreases linearly with mileage, while the CO efficiency appears to level off at approximately 10,000 miles. Since the vehicles have not accumulated sufficient mileage, these data should be used with caution.

Matthey Bishop has provided emission data for a subcompact Chrysler (U.K.) Avenger vehicle tested by Johnson Matthey with an AEC-3A catalyst and lead-sterile fuel (Ref. 8-22). The emissions from this vehicle are plotted in Figures 8-26 to 8-28. As indicated, there is essentially no deterioration in the CO and NO_x emissions. The high CO value at 24,000 miles (pre-service) is attributed to choke problems. By linear extrapolation of the HC data, the 4000- to 50,000-mile HC deterioration factor is 3.88.

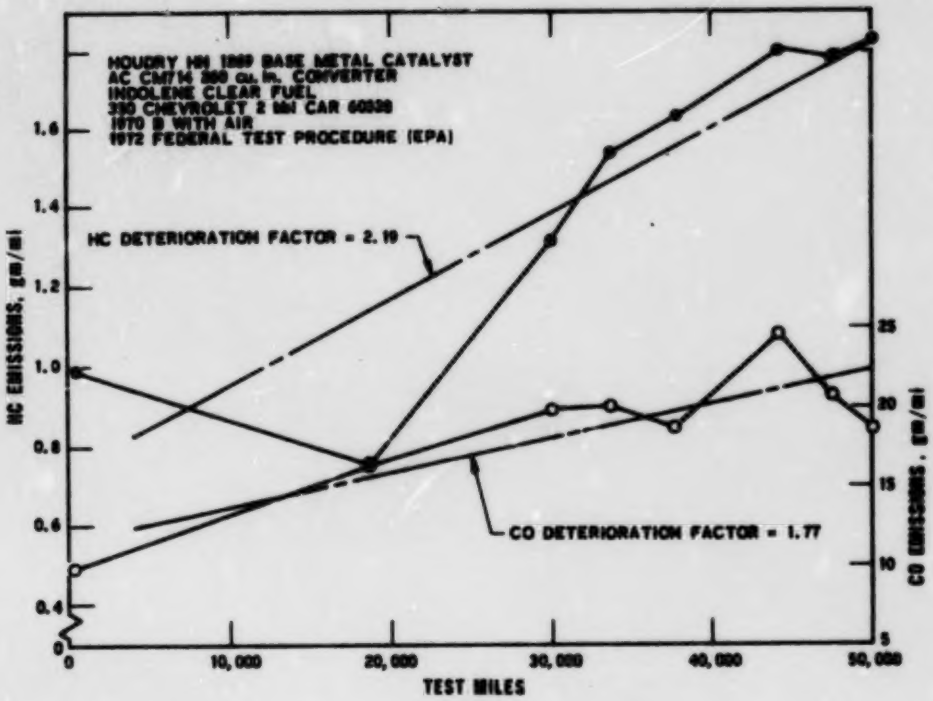


Figure 8-24. Houdry Durability Test Data

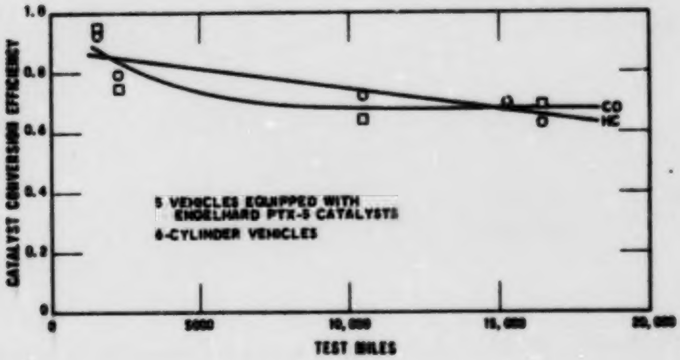
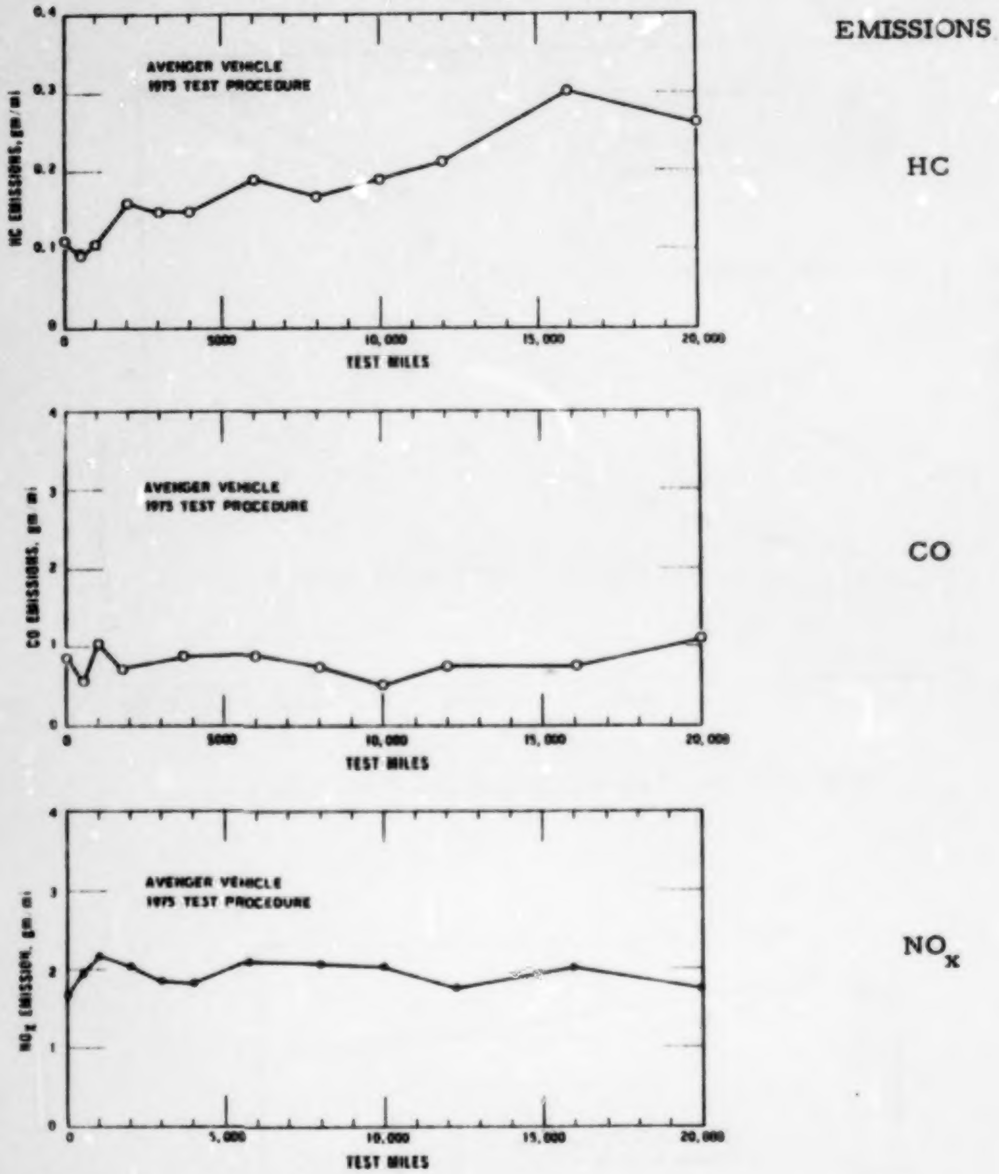


Figure 8-25. New York Police Car Fleet Data



Figures 8-26, 8-27, 8-28. Johnson-Mathey Durability Test Data

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9. INTERIM STANDARDS

9.1 SUMMARY DISCUSSION

All thirteen automobile manufacturers appearing as witnesses at the EPA Suspension Request Hearings have asked for a one-year suspension of the 1975 Federal emission standards and adoption of less stringent interim standards. In justifying their request, the automobile manufacturers contend that the technology is currently not available to achieve the 1975 standards on spark ignition, reciprocating engine-powered production vehicles. Furthermore, the automobile manufacturers are extremely reluctant to mass produce a catalytic emission control system without having successfully demonstrated vehicle/control system safety, performance, and durability. To date, there is no data available that proves that mass-produced vehicles can meet the 1975 emission standards at 50,000 miles when operated under conditions simulating customer driving patterns.

The interim standards proposed by the automobile manufacturers and a number of the catalyst suppliers are presented in Table 9-1. All of these interim standards are based upon the concept of emission averaging and, in the case of Ford, upon the satisfactory resolution by EPA of several regulatory issues, including fuel specifications, vehicle maintenance, and methane allowance. The methane allowance is proposed by Ford to account for the fact that, while the methane conversion efficiency of the catalyst is low, the reactivity of the CH_4 hydrocarbon in the smog formation process is negligible.

With the exception of Ford and International Harvester, who propose to use oxidation catalysts, the remaining auto manufacturers' suggested interim standards will be achieved by engine modifications, including improved carburetion, choke, and ignition systems.

Table 9-1. Interim 1975 Emission Standards Proposed by Manufacturers

Manufacturer	Emission Control Concept	Emissions, gm/mi			Manufacturers' Remarks
		HC	CO	NO_x	
I. DOMESTIC AUTOMOBILE MANUFACTURERS					
American Motors	Engine Modification	3.4	39	3.0	1974 Standards
Chrysler	Engine Modification	1.5 to 2.0	20 to 25	2.5 to 2.0	To be selected within that range
Ford	Oxidation Catalyst	1.6 1.5	19 19	2.0 3.1	Some models possibly without catalyst
General Motors	Engine Modification	3.4	39	3.0	1974 Standards
International Harvester	Oxidation Catalyst	1.0 to 1.15	12 to 20	3.0 to 1.75	Either combination feasible
II. FOREIGN AUTOMOBILE MANUFACTURERS					
British Leyland	Engine Modification	3.4	39	3.0	1974 Standards
Daimler-Benz	Engine Modification	1.5	20	1.5	
	Diesel Engine Without Catalyst	0.41	3.4	3.1	Meets 1975 Standards
Nissan	Engine Modification	3.4	39	3.0	1974 Standards
Saab-Scania	Engine Modification	3.4	39	3.0	1974 Standards
Toyo Kogyo	Engine Modification	—	—	—	Not selected
	Rotary Wankel Engine With Thermal Reactor	(0.41)	(3.4)	(3.1)	Good chance to meet 1975 Standards
Toyota	Engine Modification	3.4	39	3.0	1974 Standards
Volkswagen	Engine Modification	3.4	39	3.0	1974 Standards
Volvo	Engine Modification	3.4	39	3.0	1974 Standards
III. CATALYST MANUFACTURERS					
Chemico	Catalyst Addition	Technology to meet 1975 standards available			No test data supporting claim
Engelhard	Catalyst	1975 Standards or slightly higher			
W. R. Grace	Catalyst	0.6 to 0.8	7 to 10	—	
Universal Oil Products	Catalyst	0.96	7.99	—	

Daimler-Benz is optimistic with respect to meeting the 1975 standards with the diesel-powered 220D vehicle. Toyo Kogyo expressed confidence that the standards could be met with the rotary engine version of the Mazda vehicle. However, both engine types cannot be produced in sufficient quantities to create an impact on air quality in 1975-76. Furthermore, the excessive cost, the unfavorable prospects for meeting the 1976 NO_x standards, and the potential aldehyde (odor) problem are inherent disadvantages of the diesel engine.

Two catalyst manufacturers, Engelhard and Chemico, are optimistic in terms of meeting the 1975 standards, although neither one has demonstrated the required emission control system durability over 50,000 miles on the EPA certification cycle. This optimism is based on the contention that further improvements in the substrate, wash coat, and catalyst formulation are likely to occur in time to be incorporated into 1975 emission control systems. It should be recognized that suppliers would be favorably inclined toward the establishment of standards which demand the use of catalytic converters.

With the exception of Chrysler, Ford, International Harvester, and Daimler-Benz, all automobile manufacturers have proposed to adopt the 1974 emission standards for 1975 reciprocating, spark ignition engine-powered vehicles, primarily for the following stated reasons:

a. Promulgation of interim standards lower than the 1974 standards has little effect on improving air quality, as shown by NAS (Ref. 9-1).

b. Adoption of more stringent standards would tend to dilute current emission control system development efforts because the automakers might then be inclined to select 1975 systems using devices such as thermal reactors, which have little chance of ever meeting the 1976 NO_x standard.

c. Excessive risk and system cost.

The interim standards proposed by Chrysler and Daimler-Benz are of the order of 50 percent of the 1974 standards. Both companies would attempt to achieve these levels by means of engine modifications only, possibly with the use of secondary air injected into the exhaust manifolds. This basic approach is desirable because it minimizes the raw engine emissions. As a result, potential catalyst heat-load problems will be minimized in future systems incorporating catalysts.

Ford and International Harvester propose interim standards somewhat below those recommended by Chrysler and Daimler-Benz. Both Ford and International Harvester project the use of oxidation catalysts in their interim system vehicles, but Ford believes that the catalyst might be omitted on some Ford models. In this case, catalytic systems could be introduced gradually to gain the required field experience and to minimize the risk. Since the emissions from the Ford 1972 and 1973 development fleets and the engine emissions from the Ford "Riverside" fleet are substantially lower than the 1974 standards, the prospects appear favorable for this approach.

Catalyst replacement at 20,000 or 25,000 miles has been discarded by Ford on the basis of data which lead them to believe that catalyst deterioration is primarily confined to the low mileage range. However, the Ford position appears questionable in view of the vehicle durability test data submitted by American Motors, General Motors, Matthey Bishop, and Ford. As discussed in Section 8, most data from these manufacturers indicate a rather gradual emission and catalyst effectiveness deterioration with mileage accumulation. None of the other manufacturers has provided information regarding catalyst replacement between 0 to 50,000 miles.

9.2 PROPOSED INTERIM STANDARDS

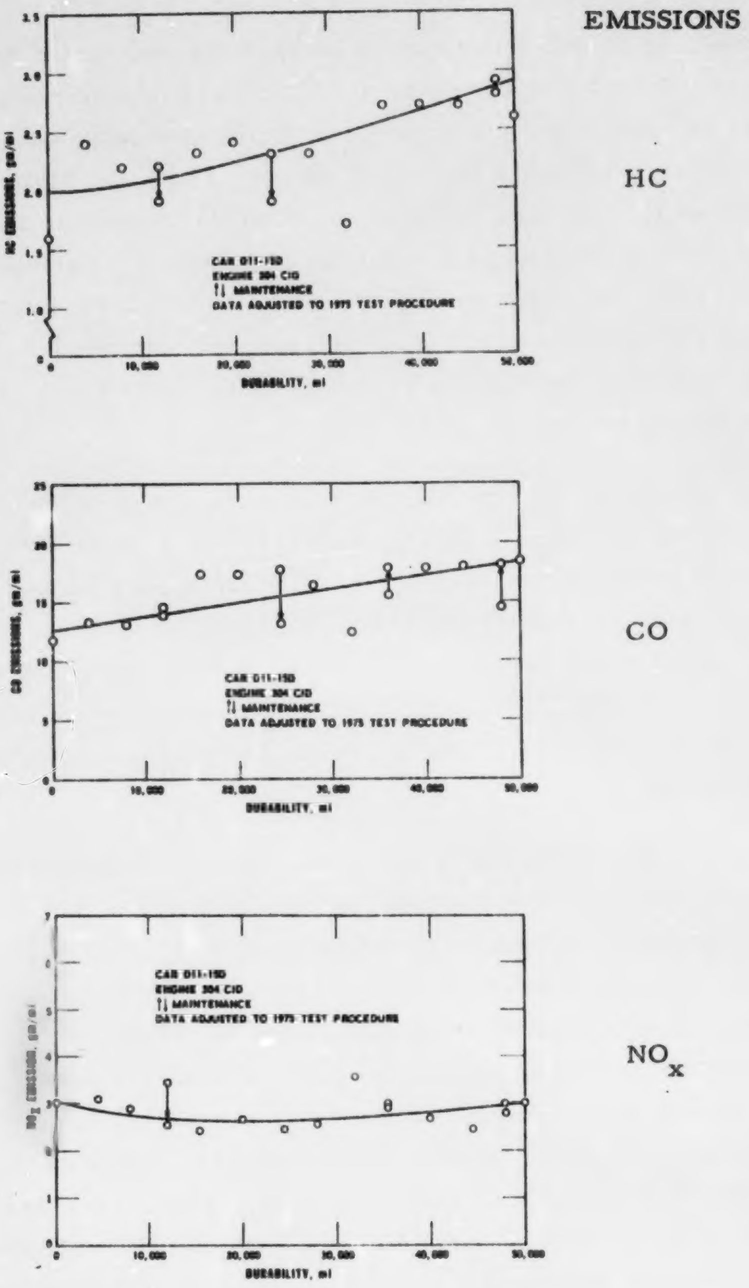
9.2.1 American Motors

American Motors considers compliance with the 1975 Federal emission standards to be technically unfeasible and recommends that the 1974 standards and test procedures be continued through model year 1975 (Ref. 9-2).

This conclusion is based on the contention that the American Motors' candidate catalytic converter system for 1975 is not sufficiently developed to be released for production within the short time remaining before critical production-related decisions have to be made. American Motors recommends that selection of interim standards be based on the degree of control that can be achieved with systems without catalytic converters. Furthermore, American Motors states that the engineering efforts currently under way on the 1975 system would be diluted if more stringent interim standards were selected for 1975 and, therefore compliance with the 1975-76 emission standards would be further delayed.

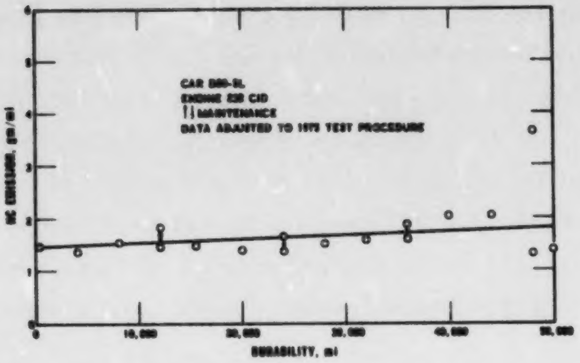
Although one American Motors vehicle (Section 8) has met the 1975 HC and NO_x standards for 50,000 miles (CO was above the standard) American Motors does not believe that the adoption of these standards can be justified on the basis of a single successful vehicle durability test over the relatively "mild" EPA route. Furthermore, American Motors points out that on that test, fuel was used with a lead and phosphorus contamination level of only approximately 50 percent of the maximum allowed by the proposed EPA fuel additive regulation.

Since the lowest HC and CO emissions achieved by 1972 and 1973 American Motors certification vehicles are substantially below the 1974 standards (Ref. 9-3), it appears that American Motors might be able to meet more stringent requirements than the proposed 1975 interim standards at least on some models. The data base for this judgment is presented in Figures 9-1 to 9-3 for a Matador 1972 certification vehicle (304CID, automatic, engine modifications) and in Figures 9-4 to 9-6 for a Hornet 1973 certification vehicle (232 CID, automatic, engine modifications). The data plotted in these figures are adjusted to the 1975 test procedure. The curves drawn represent an estimated fit to the data points. As indicated, the HC and CO emissions of the 1972 vehicles increase by a factor of approximately 1.4 between 4,000 and 50,000 miles, while NO_x remains essentially constant. While at 50,000 miles the HC level shows little remaining margin, the CO emissions are

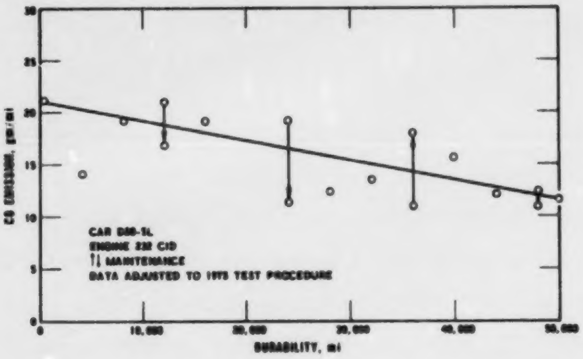


Figures 9-1, 9-2, 9-3. American Motors Matador 1972 Certification Car

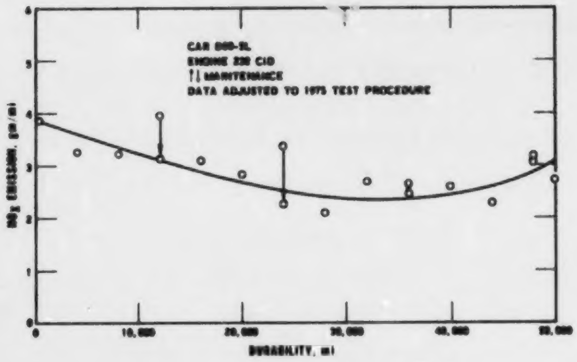
EMISSIONS



HC



CO



NO$_x$

Figures 9-4, 9-5, 9-6. American Motors Hornet 1973 Certification Car less than 50 percent of the 1974 standard. The 1973 vehicle shows increasing HC emissions and decreasing CO emissions as mileage is accumulated. No explanation was offered by American Motors regarding the trend of the CO emissions. At 50,000 miles, the HC and CO emissions are approximately 1.8 gm/mi and 11.7 gm/mi, which is substantially lower than the 1974 standard. The NO_x emissions are above the 1974 standard between 0 and 12,000 miles. Although not discussed by American Motors, it seems possible that the deterioration of the engine emissions may be reduced by means of the projected improved carburetion, choke, and ignition systems.

American Motors did not provide information on maintenance requirements, cost, and growth potential of the system projected for compliance with the 1975 interim standards proposed by American Motors.

9.2.2 Chrysler

In the opinion of Chrysler, the 1975 emission control system concepts with catalysts or any other alternative control technique cannot be reduced to practical hardware within the lead time remaining for 1975 production (Ref. 9-4). For this reason, Chrysler emphasizes and is pursuing the engine modification approach for 1975 model vehicles. The modifications currently being investigated include improvements on the current Chrysler "Cleaner Air System" and incorporation of electronic spark timing control, EGR, carburetor altitude control, and exhaust port air injection on all engines. Utilization of catalytic converters is not anticipated because of severe catalyst durability problems encountered by Chrysler to date.

With these improvements, Chrysler projects to meet the following interim standards (in grams per mile) with 1975 model vehicles:

	1974 Standards	Recommended 1975 Interim Standards	1975 Standards
HC	3.4	1.5 to 2.0	0.41
CO	39.0	20 to 25	3.4
NO_x	3.0	2.5 to 2.0	3.1

The above emission ranges specified by Chrysler illustrate the tradeoffs between maximum HC, CO and NO_x control. Chrysler states that the low limits for all these pollutants probably cannot be met simultaneously in 1975.

According to Chrysler, the purchase price of a car meeting the interim standards would be substantially lower than that of a car equipped to meet the 1975 standards. Compared with a 1974 car, the retail price increase of the two systems is $148 and $411, respectively (Ref. 9-4). The higher cost of the system meeting the 1975 standards reflects the incorporation of catalytic converter(s) and the partial thermal reactor(s) projected for that system.

The engine modifications required in the system designed to meet the proposed interim standards are compatible with catalytic converter systems which, in the opinion of Chrysler, are ultimately required to meet the 1975 standards. Incorporation of these engine modifications is considered both desirable and necessary with respect to emission control system reliability and durability, as well as vehicle driveability and safety.

9.2.3 Ford Motor Company

Ford contents that the technology to achieve the 1975 emission standards is currently not available and, as a result, less stringent interim standards should be established for 1975 model year vehicles. Based on engineering judgment, Ford believes that the following combinations of interim standards (in grams per mile) can be met with 1975 model Ford production vehicles (Ref. 9-5):

HC	1.6	1.5
CO	19.0	19.0
NO_x	2.0	3.1

Ford's selection of these interim standards is contingent upon satisfactory EPA resolution of several important regulatory issues which directly affect Ford's emission control capabilities for 1975 vehicles. These issues include allowable lead and phosphorus levels in the fuel, permission to average the emissions of certification vehicles, introduction of a methane allowance for vehicles equipped with catalytic converters, and establishment of maintenance procedures for durability/certification vehicles. Currently no data are available at Ford which demonstrate that the proposed interim standards can be achieved on production vehicles. However, Ford anticipates that sufficient progress can be made to meet these levels by 1975.

The proposed interim standards are based upon utilization of a catalyst-only system (no thermal reactor). According to Ford, these values represent the limit of the technology available for 1975 production vehicles. Although Ford anticipates that most of the 1975 vehicles will require an oxidation catalyst to meet these interim standards, some models may be certified without catalysts. In view of the low emissions achieved by Ford on the 1972 and 1973 model development vehicle fleets at low mileage and the potential improvements in the area of engine modifications, this approach appears feasible. On the average, the emissions of the Ford 1973 development fleet vehicles are 2.09 gm/mi HC, 17.15 gm/mi CO, and 2.42 gm/mi NO_x (based on the 1975 test procedure) (Ref. 9-6).

The 1972 vehicles were tested in accordance with the 1972 test procedure; average emissions of 2.37 gm/mi HC, 24.2 gm/mi CO and 2.22 gm/mi NO_x were obtained. Using the 1975/1972 conversion factors derived by Ford for the 1973 vehicles (0.90 for HC, 0.72 for CO, 1.02 for NO_x), the 1975-equivalent emissions were computed for the 1972 vehicles. On this basis, the 1972 and 1973 vehicle emissions are quite comparable. Of course, these numbers must be adjusted to account for engine emission deterioration over 50,000 miles.

Test data for the Ford Riverside fleet provided by Engelhard indicate average zero mileage "raw" engine emissions of approximately 1.45 gm/mi HC, 25.1 gm/mi CO and 2.24 gm/mi NO_x.

The interim standards proposed by Ford have been developed from projections of average emissions obtained from low mileage, best-effort catalyst-only systems developed in 1971 and deterioration factors derived from five vehicles that had completed 50,000 miles of durability testing. In addition, Ford applied a factor of 1.2 to account for test data uncertainties. According to Ford, the average sales-weighted low mileage emissions from these best-effort vehicles are 0.45 gm/mi HC, 6.5 gm/mi CO and 1.2 gm/mi NO_x. Considering the low mileage HC and CO emissions achieved on the Riverside vehicles, these HC and CO values appear to be conservatively high. The low mileage to 50,000-mile emission deterioration factors of 2.8 for HC, 2.4 for CO and 1.4 for NO_x were derived by Ford principally from the 1974 California fleet test data. Although these systems are not considered representative of 1975 configurations by the report team, the deterioration factors selected by Ford are considered reasonable approximations. These aspects are discussed in Section 8. Ford intends to develop more accurate deterioration factors upon completion of the Riverside test program. However, the Engelhard catalysts utilized on these vehicles are not of the improved type and, as a result, the emission performance of these systems may not adequately reflect current state-of-the-art technology.

Although the question of catalyst replacement and its effect on interim standards has not been fully investigated by Ford, the emissions benefit is considered small unless the catalyst were replaced at unreasonably short intervals. This conclusion by Ford is based on the data from the 1974 California fleet tests. As discussed in Section 8, these data indicate that catalyst deterioration occurs primarily during the early stages of catalyst usage. Following an initial rapid rise, the emissions remain essentially constant up to very high mileage. Since these trends are contradictory to other Ford data and to most of the data provided by other manufacturers, the rationale for the Ford conclusion regarding catalyst replacement is not readily apparent.

No information was provided by Ford on maintenance, cost and growth potential of the proposed interim system. However, the basic design of this system appears to be identical to the systems projected by Ford to meet the 1974 standards.

9.2.4 General Motors

In requesting suspension of the 1975 Federal emission standards, General Motors recommends utilization of the 1974 standards as the interim standards for 1975 model-year vehicles. General Motors states that continuing the 1974 standards for an additional year will allow them to concentrate on systems that will meet the 1975 standards at a later date, whereas more stringent interim standards might cause serious dilution of the total emissions-control effort.

To justify this position, General Motors (Ref. 9-7) refers to the NAS Study and stresses the small impact that a one-year suspension would have on ambient air quality.

Although General Motors believes that some improvement over the 1974 standards might be achieved by selective use of certain emission control system components, they are unable at this time to establish specific numbers on attainable levels for a number of reasons. These concern unresolved questions regarding fuel composition, emission averaging, assembly line testing, warranty, and recall procedures. In addition, General Motors feels that the control system performance and durability has not been adequately demonstrated. As a result, the capability of the advanced emission control system in terms of consistently achieving emission levels below the 1974 standards remains in doubt.

Considering the emissions of General Motors 1972 production vehicles at 4,000 miles (between 59 percent and 75 percent of the 1972 standards, Ref. 9-7), it appears that General Motors should be able to meet more stringent standards in 1975 than the 1974 levels.

9.2.5 International Harvester

As stated in their suspension request (Ref. 9-8) International Harvester will not be able to meet the 1975 emission standards on 1975 model vehicles.

However, assuming availability of fuel with sufficiently low levels of contaminants and application of the emission-averaging concept, International Harvester anticipates meeting either of the following two combinations of interim standards (in grams per mile):

HC	1.0	1.15
CO	12.0	20.0
NO_x	3.0	1.75

Although lower emission levels have been achieved by International Harvester on low-mileage research and development vehicles and engines, selection of more stringent standards is believed not to be justified in view of the rapid performance deterioration of current systems and the nature of the International Harvester product line. It is further suggested by International Harvester to limit the interim standards to 10 percent of a manufacturer's production volume in order to gain field experience with these emission systems on a lower-risk scale.

The emission control system that would be used by International Harvester to meet these interim standards would incorporate an oxidation catalyst, which is also a component of the system currently projected to comply with the 1975 standards.

Considering their low-volume production and the problems related to heavier-duty vehicles, International Harvester estimates the retail cost of the 1975 emission control system to be approximately $450.

9.2.6 British Leyland

Although they meet the 1975 Federal emission standards at low mileage, British Leyland suggests that the 1974 standards be adopted as interim standards for 1975 for two reasons (Ref. 9-9). First, the required durability of the projected 1975 emission control system has not been demonstrated and, second, establishment of interim standards between the 1974 and 1975 standards would not alleviate the durability and installation problems, but might divert efforts to a different system and further delay achievement of the 1975 emission standards. British Leyland also states that sufficient lead time is not available to design and develop a new or modified system to meet interim emission standards in 1975.

9.2.7 Daimler-Benz

Daimler-Benz produces a number of spark ignition engine models and one diesel engine model for passenger vehicle applications.

With respect to spark-ignition engines, Daimler-Benz has revised its earlier position (Ref. 9-10) of only being able to meet the 1974 standards on 1975 vehicles and is now of the opinion that the following interim standards (in grams per mile) can be met (Ref. 9-11):

HC	1.5
CO	20.0
NO_x	1.5

Selection of these interim standards is based on the use of an emission control system without a catalyst. Although incorporation of a catalyst might further reduce the emissions, engineering release of such a system is not feasible at this time because of the uncertainties and risks associated with current catalyst configurations.

Daimler-Benz believes that the 1975 standards (for gasoline-powered vehicles) can be met by the 2.2-liter diesel vehicle without the use of a catalyst. There are indications that NO_x emissions as low as 1.0 gm/mi could be achieved by means of adjustments in the diesel combustion process. According to Daimler-Benz, this engine cannot be produced in sufficient quantity by 1975 to have an impact on air quality.

9.2.8 Mitsubishi

Since Mitsubishi was not a witness at the recent EPA Suspension Request Hearings, there is no information available on Mitsubishi's position with respect to interim standards. However, Mitsubishi has submitted the following best-engine emission data (in grams per mile) obtained in accordance with the 1975 test procedure (Ref. 9-12):

HC	1.7
CO	23.5
NO_x	1.43

These levels, which are considered by Mitsubishi to be the ultimate that can be achieved by means of engine modifications, are similar to Chrysler's proposed interim standards.

9.2.9 Nissan

Nissan states that they are unable to meet the 1975 Federal emission standards on 1975 model vehicles, and recommends adoption of the 1974 standards for 1975 (Ref. 9-13). From the point of view of system reliability and durability, Nissan has no proven system for mass production other than that which satisfies the 1973 standards. Nissan believes that adoption of more stringent interim standards would only disrupt current efforts aimed at meeting the 1975-76 emission standards at a later date.

Considering the emissions from the Nissan 1972 certification vehicles (1.86 to 2.25 gm/mi HC, 18.2 to 19.5 gm/mi CO and 1.98 to 2.92 gm/mi NO_x), it appears that Nissan might be able to meet interim standards below the 1974 levels.

9.2.10 Saab-Scania

Saab-Scania states that the 1974 HC and CO standards should be considered as interim standards for the 1975 model year, if the 1975 standards are suspended (Ref. 9-14).

According to Saab, the emissions from their current vehicles have already been minimized by means of engine modifications to a point where further significant reduction cannot be expected without the use of thermal reactors and/or catalytic converters. To date, adequate durability and reliability of these components have not been demonstrated, and incorporation of unproven systems is not considered by Saab to be in the public interest.

Although there are indications that the emissions from the 1973 Saab certification vehicles are lower than the 1974 standards, Saab feels that adoption of standards more stringent than the 1974 values is not justified on that basis alone for two reasons. First, the certification vehicles are prototypes and not production vehicles and, second, the certification durability test is not yet complete. However, under questioning by the EPA Hearing Panel (Ref. 9-15), Saab admitted that more stringent interim standards could possibly be met by Saab 1975 model year vehicles.

Compliance with the interim standards proposed by Saab will be accomplished by means of engine modifications combined with an improved fuel-injection system.

9.2.11 Toyo Kogyo

Based on available data, Toyo Kogyo is pessimistic with respect to meeting the 1975 standards with spark ignition engine-powered vehicles (Ref. 9-16). Conversely, the prospects of meeting these standards with rotary engine vehicles are rather bright, although the 50,000-mile durability of the thermal reactor system used on that vehicle remains to be confirmed (Ref. 9-16). Since thermal reactors have been used successfully by Toyo Kogyo on current rotary-engine powered vehicles, no unsurmountable problems are anticipated by Toyo Kogyo for that vehicle type.

9.2.12 Toyota

Toyota states that the 1975 emissions standards are too stringent and far beyond its current technological capabilities. Therefore, Toyota requests adoption of the 1974 standards for 1975. Establishment of more stringent standards is considered undesirable by Toyota because current efforts aimed at meeting the 1975 standards would be disrupted (Ref. 9-17).

9.2.13 Volkswagen

Based on the results from the emission control system research and development work conducted to date, Volkswagen has concluded that the 1975 emission standards cannot be met with 1975 Volkswagen vehicles (Ref. 9-18). Therefore, Volkswagen recommends adoption of the 1974 standards as interim standards for 1975. According to Volkswagen, more stringent interim standards might result in the development and adoption of control systems having little or no growth potential. Furthermore, the effect of more stringent interim standards on air quality is minute.

9.2.14 Volvo

Volvo has stated that compliance with the 1975 standards is not possible at this time and adoption of the 1974 standards for 1975 vehicles is urgently requested (Ref. 9-19).

In the opinion of Volvo, the emissions of current engines cannot be substantially reduced from current levels by means of engine modifications and EGR alone, and catalytic converters and thermal reactors are required to meet the 1975 standards. Since the durability of these components is still an unresolved problem area, Volvo is unable to justify the incorporation of such devices into their 1975 vehicles at this time.

9.2.15 Chemico

Chemico has stated that the technology required to meet the 1975-76 emission levels is available at Chemico (Ref. 9-20), but that catalyst contamination by fuel additives must be prevented and the regulations must be modified to allow bulk catalyst addition at regular maintenance intervals. Chemico did not provide high mileage test data to support this statement.

9.2.16 Engelhard

It is Engelhard's firm belief that current efforts to meet the 1975 standards will be successful provided development programs now in progress throughout the industry are not permitted to slacken. Conversely, if implementation of the standards were postponed by one year, or if the standards were relaxed significantly, then compliance with the air quality standards would be unnecessarily delayed (Ref. 9-21).

Engelhard is not aware of any inherent reasons why the catalyst cannot last 50,000 miles providing it is not subjected to poisons or over-temperature conditions. Furthermore, Engelhard states that the likelihood of successful development of an improved, second-generation PTX catalyst before model year 1975 need not interfere with automotive companies' plans for including PTX converters in 1975 model year production planning considerations.

9.2.17 W. R. Grace

In the opinion of Grace (Ref. 9-22), it is probably not technologically feasible at this time to meet the 1975 emission standards (to 50,000 miles). Based on current Grace technology, the HC and CO standards will be exceeded between 5,000 to 10,000 miles. According to Grace the following HC and CO emission levels (in grams per mile) should be attainable for 50,000 miles:

HC	0.6 to 0.8
CO	7 to 10

These values are based upon the emissions from 1970-71 vehicles, and catalyst deterioration factors computed by Grace from test data.

9.2.18 Universal Oil Products

Universal Oil Products is very pessimistic regarding the development in the near future of a practical, cost-effective system which is capable of meeting the 1975 standards, and recommends that the following emission values (in grams per mile) be adopted as interim standards (Ref. 9-23).

HC	0.96
CO	7.99

The National Academy of Sciences' recommendations permitting catalyst change and averaging of emissions should also be adopted (Ref. 9-23).

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10. MAINTENANCE, SAFETY, AND COST

10.1 MAINTENANCE

As the levels of automobile emissions drop, proper engine and emission control maintenance can have an increasingly larger effect on air quality. At the low emission levels of cars meeting the 1975-76 standards, if a small percentage of the car population has malfunctioning engines or emission control systems, the total amount of pollutants released to the atmosphere by all of the automobiles designed to meet the 1975-76 standards could double.

Ensuring that all vehicles, engines and emission control systems are operating properly is a very difficult undertaking. Historically, for financial and convenience reasons, American car owners have not practiced preventive maintenance on a large scale, tending to perform maintenance or repairs only when vehicle performance has deteriorated markedly. Since vehicle performance may be unaffected or may actually improve if certain elements of the emission control system fail or deteriorate in their effectiveness,* it is very questionable whether the car owner will, at his option, maintain these devices in good repair (Ref. 10-1). Because of this, EPA has felt it is extremely important to certify only emission control systems incorporating designs which require minimal maintenance and repair. Accordingly, its 50,000-mile durability test procedure for certification currently restricts maintenance to one servicing of the ignition and carburetor system. No servicing of the emission control system is permitted.

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*One example is the EGR system. The recirculated exhaust is an inert diluent which effectively reduces engine size and hence power output. It also decreases fuel economy. Plugging of the EGR system or an EGR valve failure, which reduces the amount of recirculated exhaust flow, actually would improve vehicle performance. Another example is the catalyst; its failure, in most instances, would go unnoticed by the vehicle operator.

However, as a result of problems in passing the 50,000-mile durability test, EPA has presently under development proposed regulations that would allow increased maintenance under certain guidelines. These regulations contemplate catalyst replacement and other reasonable maintenance. EPA would consider approving EGR valve maintenance if the valve malfunction was such as to cause vehicle performance deterioration leading the car owner to have the defect remedied (Refs. 10-2 and 10-3). To achieve this result, it has been suggested that the EGR system should be redesigned so as to fail only in the "on" position. Several automobile companies (e.g., Ref. 10-1) have declared this to be (1) undesirable, and (2) unsafe, on the following bases: (1) if the EGR valve remains in the open position upon malfunction of the system, the car cannot be started; and (2) failure of the EGR system might cause sudden power loss at an undesirable time. Examples of the latter are during car-passing maneuvers (at wide-open throttle EGR is normally off in many systems) or during deceleration on a freeway where the engine may stall if EGR is suddenly applied, leading to loss of power brakes and steering.

Preliminary estimates of catalyst replacement cost by catalyst manufacturers range between $20 and $100, enough money to make voluntary catalyst replacement very questionable, since no vehicle performance degradation will ordinarily be incurred. Chrysler (Ref. 10-1) has suggested gradual artificially induced performance degradation, controlled by an emission sensor, as an approach to ensure catalyst replacement. No such devices presently have been invented.

The situation may be worse than indicated by the problems in attempting to pass the 50,000-mile durability test. Many of the automobile companies have expressed the opinion that the EPA durability test is a relatively easy test compared with the operating conditions to which many cars are exposed. The passing of a prescribed 50,000-mile test by a very limited number of cars does nothing but ensure that a very small part of a large fleet of vehicles is operating properly. Mandatory inspection, test, and correction of defective emission control systems of all used vehicles is another alternative to maintenance-free systems, but it too has its problems, e.g., cost, inconvenience, lack of a suitable test, and long periods of vehicle operation between tests.

In summary, it can be stated that no effective approach has yet been found which will ensure that the emission control system on practically all cars will continue to function properly.

10.2 SAFETY

10.2.1 General

The primary safety issues associated with proposed 1975-76 automobile emission control systems are:

a. Poor car-passing performance.
b. Increased fire hazard.
c. Possible sudden and catastrophic failures during critical situations of automobile components (such as ignition or fuel system) due to the excessive heat of the emission control system.

10.2.2 Poor Passing Performance

With 1975-76 emission control systems, car-passing performance may be degraded because of the use of EGR, changes in spark ignition timing for emission control, higher exhaust system engine backpressure, and lower compression ratios required by the use of unleaded gasoline necessitated by lead-sensitive catalyst systems.

Some manufacturers propose to cut off EGR at wide-open throttle in order to retain as much performance as possible. Some manufacturers have indicated that it may be necessary to drop several of their lower-powered economy models in order to achieve safe driveability.

10.2.3 Fire Hazard

The possibility of increased fire hazard in automobiles equipped with 1975-76 emission control systems is due to the higher temperatures in the exhaust system (including the thermal reactor and/or catalytic converter). These increased temperatures are the result of the oxidation of the HC and CO emissions and are highest when the engine is operated at a very rich mixture. The worst operating conditions are:

a. Choked engine operation (particularly bad with an engine which is cranked a long time before starting and which accumulates fuel in the catalyst system).

b. High-power operation for a long period of time, e.g., very high highway speeds or when pulling a trailer on freeways or mountain grades. (To increase power, the engine is operated richer.)

c. Coasting for a long period of time, e.g., descending a mountain grade (very rich mixture engine operation).

d. High altitude operation without altitude compensation features in the engine fuel control system (results in rich engine mixture).

e. Misfiring spark plug which causes engine exhaust enrichment.

f. Engine mixture enrichment to reduce NO_x emissions and/or enhance thermal reactor emission reduction performance.

Proposed approaches to reduction or elimination of the increased fire hazards and some of the problems associated with these approaches are:

a. Time limit on engine cranking (highly inconvenient).

b. Carburetor modification to prevent engine enrichment under high-power operating conditions (reduces engine performance, does not protect against a misfiring plug, may result in poor driveability, and particularly for 1976, nonachievement of the NO_x standard).

c. Reduction of heat emission from the exhaust system by insulation and/or forced-air cooling.

d. Overtemperature sensor which reduces secondary air flow or activates exhaust by-pass for thermal reactor or catalyst (very high protective system reliability is a must; if this is the only protection system, it may be activated many times during the life of the car).

The overall fire hazard situation assessment of the automobile companies, at least for 1975, ranges from serious concern to reasonably happy. No one who is depending on an overtemperature-controlled by-pass valve is extremely confident of achieving a satisfactory solution to the fire hazard problems of the emission control system.

10.2.4 Catastrophic Component Failures

The combustion of fuel-rich engine exhaust in the emission control system can raise engine compartment temperatures significantly. Located in the engine compartment are many vital vehicle components which can malfunction in an unsafe manner as a result of these high temperatures. Examples of such malfunctions are the breakdown of electrical insulation on wires for the ignition and lights, which could cause sudden loss of power or headlights at critical times; vapor lock in the hydraulic brake or power steering systems; loss of vacuum for power brakes due to hose failure; and fuel system vapor lock.

The problems caused by high engine compartment temperatures have caused many automobile manufacturers to reject thermal reactors. Other approaches to alleviate engine compartment temperature problems are the insulation of critical components or heat sources such as catalysts. With respect to catalysts, the preferable approach has been to try to locate them outside of the engine compartment. But this has the disadvantage of making rapid catalyst warm-up difficult and of increasing emissions during a cold start.

10.3 COSTS

10.3.1 General

The major factors to be considered in evaluating the cost of an emission control system are:

a. The increase in the purchase price of the car due to the addition of the emission control system.

b. Any increased maintenance cost for the car over its lifetime as a result of the addition of the emission control system.

c. Any increased fuel cost over the life of the car due to the addition of the emission control system. This includes fuel cost increases due to increases in the cost per gallon of fuel and decreases in engine efficiency.

10.3.2 Increased Purchase Price

Some estimated increases in "sticker price" of cars equipped with emission control systems to meet 1975 standards, over an uncontrolled emission vehicle, are discussed in the following paragraphs.

10.3.2.1 American Motors

American Motors estimates the cost of its projected 1975 system to the customer at $255 (Ref. 10-4). The projected 1975 system is similar to the Ford HC/CO catalyst system although it is not clear whether the American Motors system incorporates a catalyst by-pass protection system.

10.3.2.2 Chrysler

Chrysler estimates the cost of their first-choice 1975 system at $412 (Ref. 10-1). This system is the same as the Ford HC/CO catalyst system plus a small or "partial" thermal reactor. (The addition of the thermal reactor could explain the cost differential between Ford and Chrysler.)

10.3.2.3 Ford

Ford has estimated costs for a number of potential 1975 emission control systems as shown below (Ref. 10-5). All systems include, in addition to the components shown, EGR, secondary air pumps, modified carburetors and distributors, and induction-hardened valve seats.

	Projected Customer Retail Cost, $
HC/CO Catalyst	370
Thermal Reactor	400
Dual HC/CO Catalyst*	440
HC/CO Catalyst plus Thermal Reactor	510
Dual HC/CO Catalyst plus Thermal Reactor	580

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*As used here, the dual catalyst has one HC/CO catalyst near the front of the vehicle and an additional one near the rear.

10.3.2.4 General Motors

The estimated increase in retail price of a vehicle equipped with the projected 1975 General Motors emission control system is $300 (Ref. 10-6). The emission control system is similar to the Ford HC/CO system. (The $70 difference in price may be due to the incorporation of a catalyst overtemperature control in the Ford system.)

10.3.3 Maintenance Costs

Maintenance costs include tuneups and parts replacement (such as spark plug or catalyst replacement) necessary to keep emissions at a low level. Very little factual information is available on the consumer-use maintenance required for cars equipped with emission control systems meeting the 1975-76 standards because of the limited field experience with these systems. There have been various opinions offered on the cost of catalyst replacement or refurbishment. The costs estimated per refurbishment have ranged from $20 to over $100. The low numbers correspond to replacement of pellets only, in a pellet-type catalyst. If catalyst refurbishment were necessary every 25,000 miles and the cost per refurbishment were on the high side of the cost range discussed above, a major increase in car maintenance costs would result.

10.3.4 Fuel Costs

Fuel costs of automobiles capable of meeting 1975-76 standards will be higher than those of uncontrolled vehicles, because of higher fuel consumption projected for the 1975 vehicles. This loss in fuel economy is due to the incorporation of the emission control system, reduction of the engine compression ratio, and increased vehicle weight. Chrysler has stated that the fuel economy (miles per gallon) of its cars for 1975 and 1976 will only be 81 percent and 70 percent, respectively, of that of a pre-emission control car; e.g., 1968 year model (Ref. 10-7). The 1976 fuel economy could improve significantly if a suitable NO_x catalyst were developed, but progress to date on such development has not been encouraging.

Chrysler's projected fuel economy degradation is typical of that reported by other manufacturers. Causes for the poor fuel economy are:

a. Decreased compression ratios (due to the use of lower octane number unleaded gasoline because catalysts will not tolerate leaded gasoline).

b. Ignition spark timing changes to maximize emission control rather than fuel economy.

c. EGR for NO_x reduction.

d. Operation at richer air/fuel ratios to maintain acceptable and safe driveability with EGR.

For the range of fuel economy reductions indicated above, the fuel cost increases over a car's lifetime (85,000 miles average) are estimated to be of the order of $500 for 1975-type systems and $1000 for cars equipped with 1976-type emission control systems, an amount which is larger than the increase in the sticker or purchase price of the car due to the addition of the emission control system. If every car on the road eventually had emission controls of this type, the nation's increased fuel cost would be $5 to $10 billion annually, and of course the rate of depletion of crude oil reserves would increase markedly. Development of emission control systems which permit better fuel economy is obviously highly desirable.

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11. PRODUCTION LEAD TIME

11.1 INTRODUCTION

11.1.1 Data Sources

The primary sources of data for the discussion of automotive production lead time presented in this section are (a) past and current submittals by the automobile manufacturers pertaining to progress in the development of emission control systems for 1975 model year cars, (b) testimony given in the recent EPA hearings on the request for suspension of the 1975 Federal exhaust emission standards, and (c) data available in the open literature on lead time requirements for the production implementation of new automotive vehicle designs. The pertinent information acquired from these sources is less than adequate for a detailed treatment of the lead time topic; the data are used solely to highlight some general points in the discussion that follows.

11.1.2 Terminology

Production lead time is defined as the period between commitment by management of capital funds for production facilities and the date of achievement of the first mass-produced article. This period is selected by the manufacturer so as to provide sufficient time to specify, design, procure, install, and checkout production tooling and equipment and to accelerate the manufacturing process to full-volume output. Normally, the commitment of funds for production is not made until "proof-of-design" prototype testing has been completed and the suitability of the basic design and operating features of the system has been established or verified.

11.1.3 Schedule Considerations

The operations which must be accomplished during the production lead time interval include: production engineering, tool construction and tryout, pilot assembly, and production build up. In addition to allotting time for these activities, sufficient time must be provided for contingencies such as delays due to equipment, labor, or material shortages; labor strikes; and equipment checkout problems. Accordingly, the lead time must be lengthened, to a degree governed partly by past experience and the complexity of the product to be manufactured. Frequently, as in the case of a program with a fixed end date (the first day that full production capacity is reached), economic considerations demand that a large amount of time be reserved to minimize the possibility of missing the designated milestone. However, overly conservative scheduling can lengthen the lead time excessively which then increases labor costs. Conversely, the compression of lead time can also lead to increased costs because of the need for overtime labor in both the automobile and supplier manufacturing facilities.

In summary, lead time is governed largely by equipment procurement/installation/checkout time and by the need to minimize program costs; it is flexible to the extent that the duration is defined on the basis of a number of judgment factors.

Over the years, the transition from hand labor to machine tasks and then to computer-controlled automated operations has led to increased lead times. This has naturally arisen from the requirement by the equipment manufacturers to devote more time to the design and checkout of the highly specialized and sophisticated equipment required for modern, high-volume-rate assembly line operations. Great care in equipment design and assembly line design is necessary because the magnitude of the associated economic investment reduces the allowable margin for error.

11.2 PACING ITEMS

With regard to 1975 emission control systems components, each manufacturer has identified one or more factors which control or define his production lead time requirement. In each case, the most critical items cited were the fabrication of the catalytic converter and the completion of durability tests currently being conducted for the verification of the complete emission system design. The manufacturing schedule for catalytic converters is lengthy; it is believed that this is due primarily to the fact that the converter design represents a new technology and, in contrast to most automotive components, involves a source of supply that is unfamiliar with and unproven by automotive industry experience in high-volume production practices, procedures, and requirements. Hence, the lead time requirement encompasses the additional uncertainties and contingencies associated with new vendor associations.

The following paragraphs discuss the particular manufacturing/lead time problems emphasized by the major domestic automobile manufacturers.

Of great concern to the automobile manufacturer is the need currently to commit to production the design of the engine, chassis, and body without full knowledge of the impact of emission control equipment on these major pieces of hardware. Design modifications after a period of time become very costly in terms of overtime labor necessary to adhere to schedules.

11.2.1 American Motors

American Motors states that body/frame changes required to accommodate the catalytic converter are the critical pacing lead time items. Production drawings for these body changes must commence on June 1, 1972 (Ref. 11-1).

11.2.2 Chrysler

Chrysler's decision on the type of catalyst to be used in its emission control system is the critical pacing item. It has stated that the final system definition is required 31 months prior to the start of production (January 1972). Formal commitment to a catalyst supplier is required 28 months prior to the start of production (April 1972) (Ref. 11-2).

11.2.3 Ford

While tooling is not a controlling factor, Ford's overall lead time requirement is based on the time required to prove out new hardware facilities and equipment and to redesign its mass production processes. In association with Engelhard, the catalyst supplier, two facilities are planned for the production of the catalytic converter. One of these, Plant #1, is a pilot production plant due to be in full operation by April 1, 1973 (ultimately, the plan is to convert this plant to a production facility). The other facility, Plant #2, is due to be in full operation by April 1, 1974; site procurement was planned for May 1, 1972. A decision on the source of supply for the catalytic converter canister has not been made. (Ref. 11-3.)

11.2.4 General Motors

General Motors' longest lead time requirement concerns the fabrication of electron beam welders to be used in the mass production of the catalytic converter canister. Six welders are required for full-volume production and the total lead time for this equipment is 24 months. General Motors states that in order for this equipment to be available for 1975 model year production purchase orders must be placed by July 1, 1972. Production welding experience is lacking for the new corrosion-resistant steel used for the canister and new welding techniques must be tested and evaluated. With regard to other components in the proposed 1975 emission control system--such as the carburetor, electronic ignition, and quick heat manifold--the lead time is paced by capital equipment acquisition and the period required for field tests. Lead time for these components is not critical (Ref. 11-4).

11.3 AUTOMOBILE MANUFACTURERS' SCHEDULES FOR CATALYTIC CONVERTERS

Since the catalytic converter appears to be a pacing production development item with which all of the manufacturers must contend, it serves as a consistent basis for examining and comparing production schedules and lead times among the different manufacturers. The data available for this comparison are shown in Figure 11-1.

In general, the agreement in the catalytic converter production milestones among the various manufacturers is good. Exact agreement between Ford and American Motors Milestone C, facilities contract, is noted; both manufacturers reference this milestone to the Engelhard facilities development. Among all the manufacturers represented, the overall lead time requirement ranges from 25 to 28 months.

The schedules shown for the two foreign manufacturers are referenced to a decision date for selecting the type of converter to be used in their 1975 systems. This date appears to be a couple of months downstream from the equivalent decision point for the domestic manufacturers. The reason for this is not known; however, the difference is not significant.

11.4 CATALYST SUPPLIERS' SCHEDULES

Schedules submitted in the suspension request hearings by the catalyst suppliers are shown in Figure 11-2 in comparison with the Figure 11-1 suppliers' schedule submitted by Ford. The corresponding sets of data from these two figures are found to be in agreement. If the lead time reference point is fixed at the date of firm commitment, it is seen that the lead times estimated to be required by the various catalyst suppliers vary in a narrow range from 21 to 25 months. The differences in lead time may be due to varying degrees of optimism in estimating the facility construction and equipments schedule.

From Figure 11-2, and allowing for the fact that production catalysts must be available at the manufacturer's plant in advance of first vehicle production, the automotive manufacturers' lead time requirement would be expected to be approximately 2 years. This is consistent with the Ford lead time requirement shown in Figure 11-1 as 28 months. Since the schedules of the automotive manufacturers are in good general agreement, it is

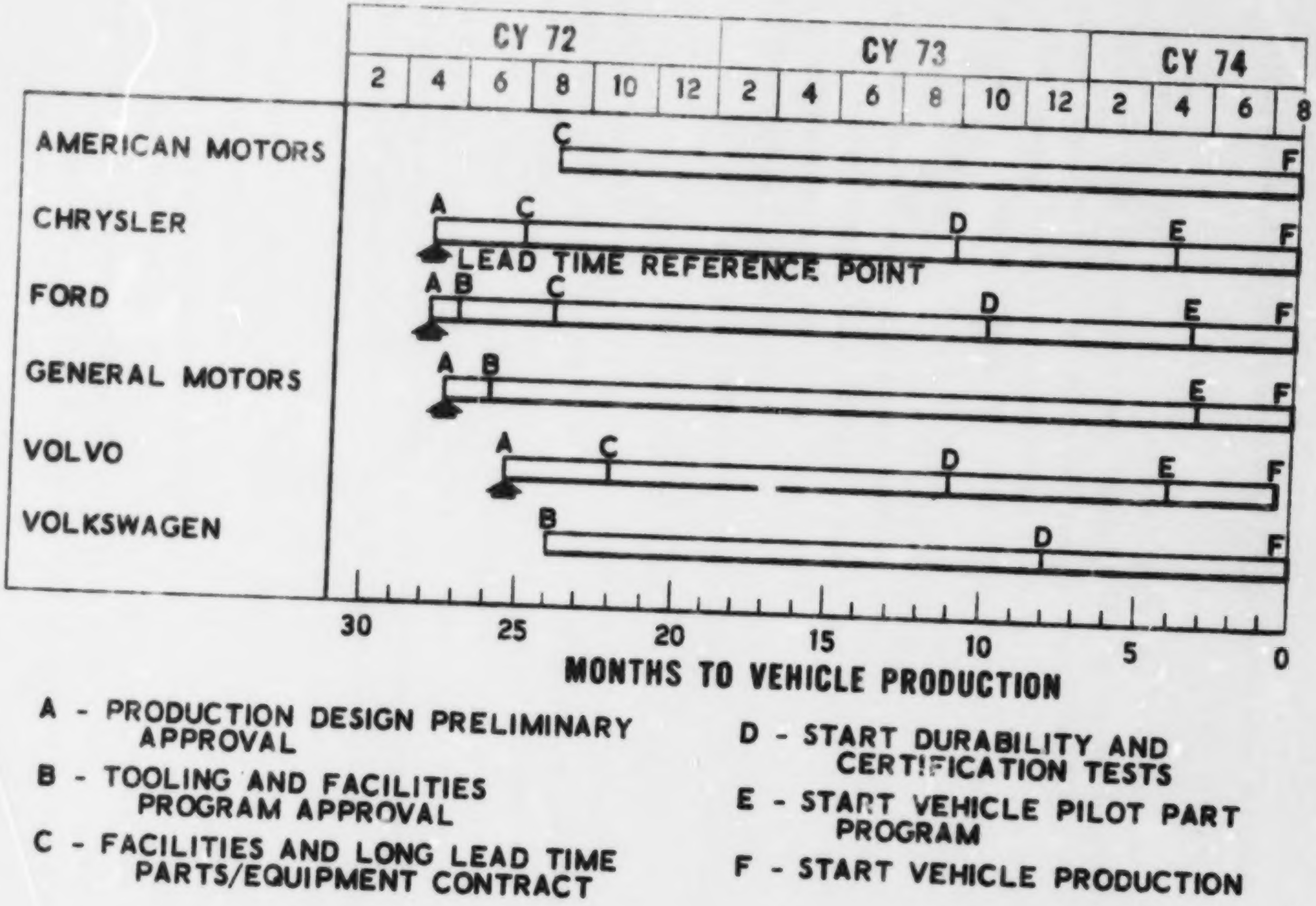

Figure 11-1. Significant Milestones for Catalytic Converter Production (Data Supplied by Automobile Manufacturers)

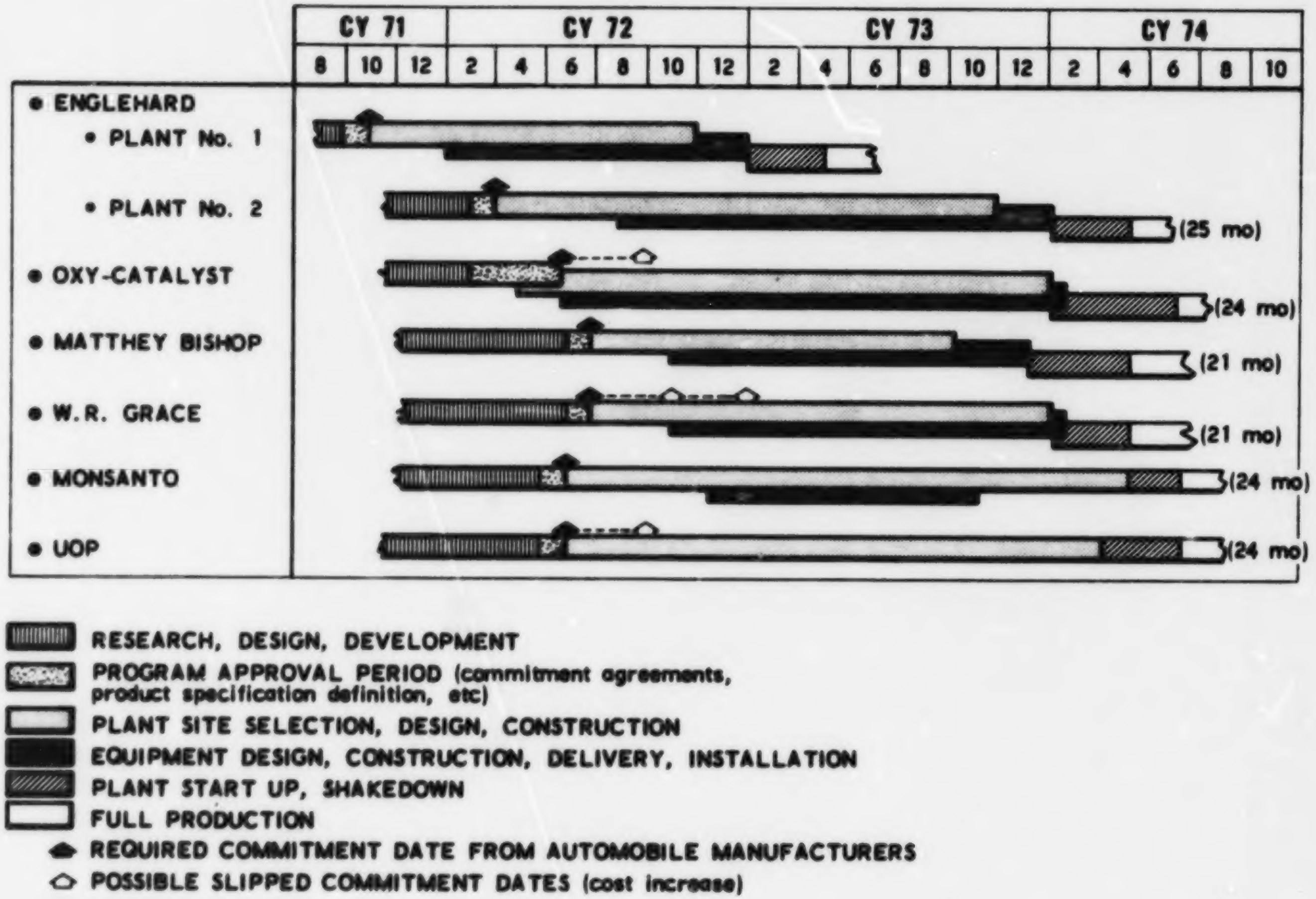

Figure 11-2. Representative Catalyst Production Lead Time Schedules

concluded that there are no gross inconsistencies among or between the lead time specifications of the suppliers and manufacturers.

11.5 CONTRACTUAL COMMITMENTS WITH SUPPLIERS

The Ford/Engelhard relationship represents the only case to date of a contractual commitment between an automobile manufacturer and a catalyst supplier. Ford has contracted with Engelhard Industries for supplying catalysts to be used in its emission control system and has provided financial backing of up to $4.9 million for facilities and equipment. Ford is also considering other sources of supply but no other contracts have been initiated to date. Other automobile manufacturers are also evaluating multiple sources of supply for catalysts but have not made contractual commitments as yet.

11.6 SCHEDULE INTEGRATION

An example of the integration of a supplier schedule with that of an automobile manufacturer is shown in Figure 11-3 for the Ford/catalyst supplier relationship. The Ford production milestone schedule taken from Figure 11-1 is compared in Figure 11-3 with the Engelhard Plant #2 facility construction program and with the construction program for other catalyst platers and for substrate suppliers.

Milestone C in the Ford schedule represents the supplier facilities contract award and this may be seen to correspond with the initiation of construction in the Engelhard schedule. The build up to full production in the Engelhard schedule corresponds to the Ford milestone for the completion of the production sample build, immediately preceding milestone E, which is the start of vehicle pilot production. At this point, the supplier's production output must be available for Ford's pilot assembly operation.

Ford is negotiating with other catalyst platers, and their schedules for plant construction, tooling and production corresponds well with the Engelhard schedule.

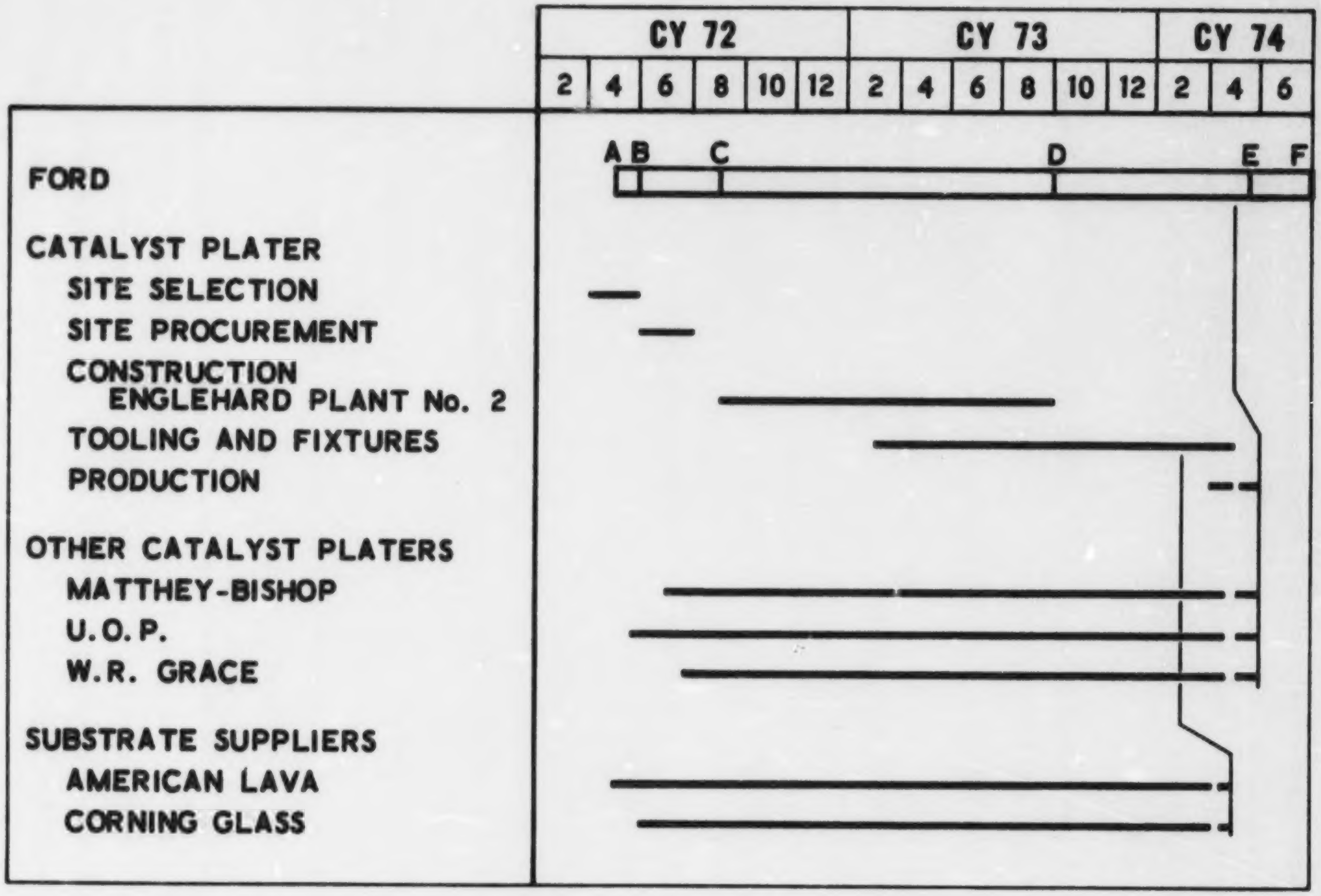

Figure 11-3. Catalytic Converter Program Timing (Ford)

For the substrate construction, Ford has made purchase commitments with American Lava, and may presently be making commitments to another substrate supplier. The timing for the development of these supplier facilities is about 24 months, or approximately the same as for the Engelhard facility development.

In general, the scheduling duration seems to be consistent between the manufacturer and the suppliers.

11.7 SCHEDULE COMPRESSION AND COST INTERACTIONS

All manufacturers have indicated that their current schedules represent an accelerated work effort in order to develop production facilities in time for the 1975 model year. An example of this schedule compression is given by Chrysler (Figure 11-4). A reduction of one full year in lead time is shown; this appears to have been accomplished mainly through a delay in the start of the production design and test phase and an increase in the overlap of this phase with other work efforts. Notable is the lack of schedule change in the design release phase.

Additional schedule compression holds higher risks for the automobile manufacturer because of major reductions in the time allowance for correcting problems in production hardware design or assembly line operations; this effect is only correctable to a degree through the use of labor on overtime which in turn raises product cost. Some compression is afforded if the original program goals are revised. Ford estimated an added gain of 3 to 3-1/2 months over its accelerated schedule if its proposed interim emission standards were adopted (see Figure 11-5).

Some catalyst suppliers have estimated an ability to further compress their schedules by 3 to 6 months (Figure 11-2) but with corresponding increases in unit costs from approximately 3 to 12 percent. At this time there is insufficient information to accurately correlate the increase in unit cost with schedule compression for either catalyst or automobile manufacturers.

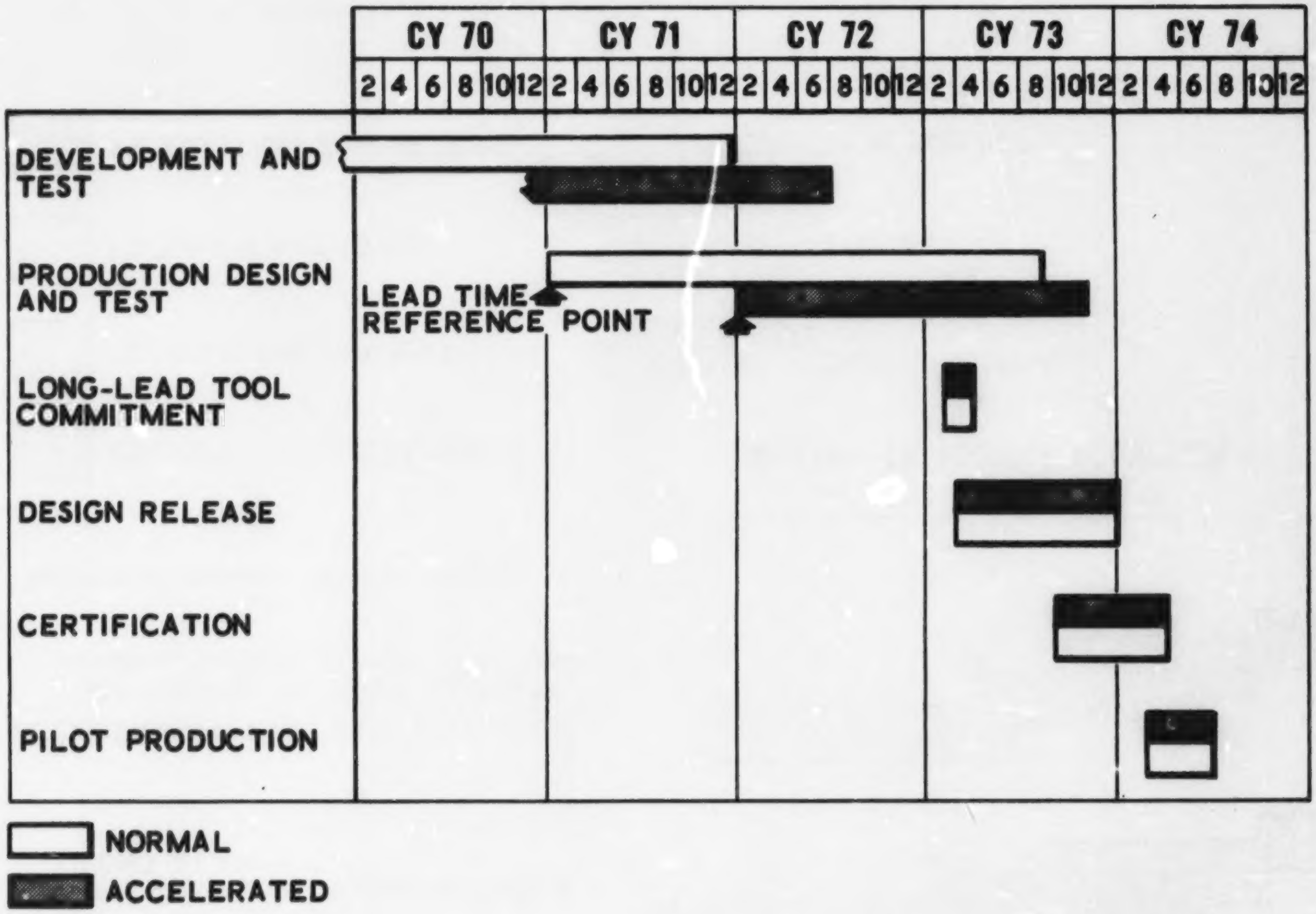

Figure 11-4. Comparison of Chrysler Production Design Schedules (1975 Emission Control System)

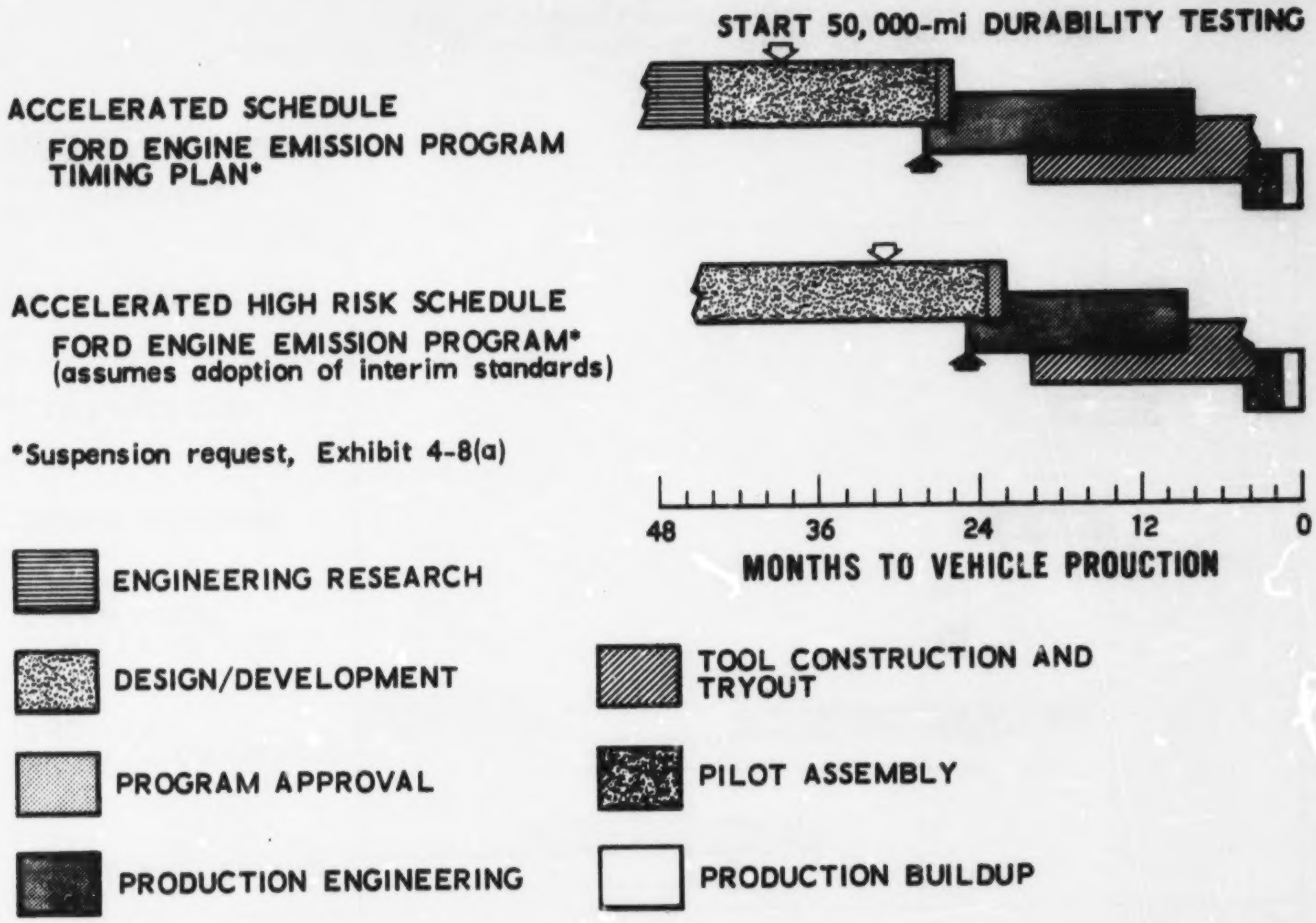

Figure 11-5. Accelerated Development Schedules

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12. UNCONVENTIONAL AUTOMOTIVE ENGINES

Unconventional automotive engines are those other than the reciprocating spark ignition internal combustion engine. They include the Wankel, diesel, gas turbine, stratified charge, Rankine, and Stirling engine classes. The following sections briefly describe the salient features of each engine type and summarize the status of the automotive industry development efforts.

12.1 WANKEL (ROTARY) ENGINE

The Wankel engine, although in the spark ignition internal combustion class, is entirely different mechanically from the conventional reciprocating engine. Instead of reciprocating pistons and valves, this engine contains one or more triangular-shaped rotors which rotate on an eccentric shaft in a rotor housing. The volume between the rotor and the housing varies as the rotor turns to first achieve compression of the air/fuel mixture and then expansion of the products of combustion.

Compared with the conventional reciprocating engine, the Wankel is smaller in weight and volume for the same power, has very low levels of vibration since there are no reciprocating masses, and can run on very low octane number fuels; its untreated exhaust contains somewhat more HC, approximately the same CO, and much less NO_x; its cost in large volume production is expected to be less, and its fuel economy the same or poorer, depending on the particular design.

12.1.1 Ford

Ford's Wankel engine program includes both dynamometer and vehicle phases (Ref. 12-1). The dynamometer phase is concerned with optimization of a Ford-designed Wankel engine and additional emission control system components. The current vehicle phase is concerned with evaluation of a Mazda RX-2 vehicle (Toyo Kogyo Wankel engine) equipped with Ford emission control devices. The best emission results obtained by Ford on a carefully timed Mazda rotary engine vehicle are 1.3 gm/mi HC, 24 gm/mi CO and 0.66 gm/mi (1975 test procedure).

Ford believes that a thermal reactor, a catalytic converter, and exhaust gas recirculation will have to be used with the Wankel engine to meet 1975-76 emission standards. Results from the Mazda test vehicle are expected from the Riverside test facility in late 1972; test results from a vehicle incorporating a Ford-designed Wankel are expected in mid-1973.

If the development program is successful, Ford estimates that it would then require at least 42 additional months to begin production of the engine.

12.1.2 General Motors

General Motors has conducted an intensive study and development program on the rotary combustion Wankel engine for two years (Ref. 12-2). Base engine emissions for the General Motors Wankel engine are somewhat higher in HC, about the same in CO, and slightly lower in NO_x than the conventional G.M. reciprocating engines. Hence, both thermal reactors and catalytic converters have been applied to the rotary engine. Possible advantages of the Wankel are visualized to be primarily in the areas of reduced size and weight, which could permit the utilization of some emission control systems not suited to the conventional engine (e.g., a large thermal reactor).

The 1975 standards have been achieved at low mileage (by a small margin) with a Wankel-powered 2500-lb vehicle incorporating air injection in the exhaust manifold and a monolithic noble metal catalyst (no EGR). The manufacturer believes that the durability problems of the catalyst will be similar to those encountered with conventional engines.

General Motors has not been able to achieve the 1975 standards with a thermal reactor alone; the best single test was marginal on HC, over on CO, and consistently below 1 gm/mi on NO_x. General Motors states they suspect that the reason that they were not able to make the 1975 standards at low mileage with the thermal reactor alone, while Toyo Kogyo did accomplish this, is that the fuel economy of its Wankel engine is similar to that of conventional reciprocating engines while the Toyo Kogyo Wankel was 25 to 30 percent poorer. General Motors NO_x test results tend to belie this contention as they were consistently in the 0.5 to 0.7 gm/mi range; these satisfactory NO_x emission results were attributed to running rich to obtain good performance from the thermal reactor.

General Motors states they cannot produce Wankel engines for 1975 model year cars, except on a very limited basis.

12.1.3 Daimler-Benz

The Daimler-Benz Wankel engine is in a predevelopment state (Ref. 12-3). It has been installed in a vehicle with an emission control system consisting of a monolithic oxidation catalyst, EGR, air injection, and retarded ignition. Emission test results (gm/mi) are 0.34 for HC, 2.49 for CO, and 1.24 for NO_x (averages of 21 tests).

Daimler-Benz states that production of Wankel engines for model years 1975-76 is not possible.

12.1.4 Toyo Kogyo

Toyo Kogyo presently produces rotary-engined cars at a low production rate (15,000 cars/month versus 25,000 cars/day for General Motors) (Ref. 12-4). This company has met the 1975 standards at low mileage with a 2750-lb vehicle equipped with a 70-CID two-rotor Wankel and a thermal reactor (no

EGR). Emission results (in grams per mile) were 0.17 for HC, 2.2 for CO, and 0.93 for NO_x (averages of 18 tests). These values satisfy Toyo Kogyo engineering low mileage goals.

Toyo Kogyo has not demonstrated 50,000-mile durability but is optimistic about this performance capacity. Equivalent engine dynamometer tests have successfully been completed; the thermal reactor used is very similar to the one now on its 1972 rotary engine cars. The Toyo Kogyo thermal reactor is unique from that developed by other manufacturers in that it is force cooled by air from the secondary air pump which results in relatively low reactor material temperatures and low heat rejection to the engine compartment. Emission performance for the 1975 prototype system was improved over the 1972 system by carburetor and ignition system modifications and modulation of the secondary air system. These changes resulted in sizable emission performance improvements during the engine warm-up portions of the emission tests (Ref. 12-5).

Toyo Kogyo's projected 1975 car has a fuel economy loss of five percent compared to their 1972 model. However, Ford and General Motors claim their 1972 small economy cars (e.g., Vega, Pinto, etc.) have 25 to 30 percent better fuel economy than the Toyo Kogyo 1972 rotary engine vehicles.

The maximum production rate estimated by Toyo Kogyo for 1975 is 50,000 to 70,000 cars per month.

12.2 DIESEL ENGINE

The diesel engine, widely used in heavy-duty vehicles (trucks, buses, etc.), has the potential for low emissions without aftertreatment of its exhaust. Test procedures for light-duty diesel-powered vehicles have not been firmly established. However, on the basis of anticipated procedures and current test results, it appears that the 1975 standards are achievable without exhaust treatment by the Mercedes 220D vehicle (Ref. 12-3).

The diesel achieves low HC and CO emissions by operating at high compression ratios and very lean air/fuel ratios. However, operation in the lean air/fuel ratio regime precludes utilization of a NO_x catalyst, which requires a reducing atmosphere. Tests with the only other alternate methods of reducing NO_x emissions, e.g., EGR and retarded injection, to date indicate the 1976 standards are not achievable by a diesel.

The high compression ratio and lean air/fuel ratio of the diesel result in its being a very large and heavy engine. Daimler-Benz indicates that the size and weight problem may be so acute that it is impossible to build a diesel-powered car with sufficient power to meet the passing requirement of the DOT safety car (Ref. 12-6).

Initial cost of the diesel is more than for a conventional reciprocating gasoline engine of the same power. Daimler-Benz has indicated an increased cost of $1500 for the diesel over the gasoline engine (120-horsepower engines). Daimler-Benz presently sells a 62-horsepower diesel car which is economically attractive for some markets where its fuel economy and long life are important (e.g., high mileage commercial uses where gasoline prices and horsepower taxes are very high (Ref. 12-6)).

No other automobile manufacturers foresee the diesel as an attractive approach to meeting the 1975-76 standards. Their expressed reasons are essentially the same as discussed above, plus a concern for the diesel's distinctive exhaust odor.

12.3 GAS TURBINE

12.3.1 General

The gas turbine operates at very lean air/fuel ratios with correspondingly low maximum temperatures in the engine as compared with a reciprocating engine. Hence, the HC and CO emissions of the engine are low. It is hoped that no aftertreatment devices will be necessary. Chrysler states that its engine would meet the 1975 standards. To date no automobile manufacturer has succeeded in meeting the 1976 NO_x standards, although some are encouraged by their test results.

Ford, General Motors, and Chrysler all have passenger car gas turbine programs. In addition to the emission problems discussed above, they indicate other problems, including: (a) high cost, (b) poor fuel economy at part-load, (c) requirement for large quantities of nickel, and (d) poor acceleration characteristics (Refs. 12-1, 12-2, 12-7).

All manufacturers indicate that sizable production is not possible until the 1980s.

12.4 STRATIFIED CHARGE ENGINE

12.4.1 General

The term "stratified charge" characterizes the most significant difference between this type of engine and the conventional reciprocating internal combustion engine. At the commencement of combustion, the air/fuel mixture is not homogeneous but purposely made locally richer (or "stratified") near the spark plug. Improved fuel economy and possible multifuel use were the original reasons for interest in this type of engine.

The engine may permit the achievement of low NO_x emissions without an NO_x catalyst and with relatively satisfactory fuel economy. This is possible because the local richness permits higher EGR rates without misfire for the same engine air/fuel ratio and results in reduced peak combustion temperatures. A thermal reactor and/or catalytic converter will be necessary for HC/CO emission reduction. Hence, this engine is of interest primarily for 1976 standards since the 1975 NO_x standard can be met with a conventional reciprocating engine.

12.4.2 Ford

Ford has built and tested a 141-CID engine in an M-151 MUTT (army vehicle of 3000-lb gross weight (Ref. 12-1)). The engine design also has been adapted to a 141-CID Capri engine and to a 351-CID V-8 engine for a Torino. Emission results (in grams per mile) from the MUTT program are:

	HC	CO	NO_x
Average of 14 EPA tests	0.37	0.93	0.33
Average of 4 Ford tests	0.34	1.01	0.35

It should be noted that the test vehicle was unable to follow the CVS acceleration schedule because of insufficient power. Such reduced acceleration also normally would reduce NO_x emissions from a conventional engine.

The major problems encountered with this type of engine at the present time include the following:

a. A production-feasible design for the injector is not available.
b. Engine operation still encounters misfire at high EGR rates.
c. Durability of some engine components (such as spark plugs) is questionable.
d. The HC/CO catalyst durability problems of the conventional engine also must be solved.

Ford estimates the earliest possible date for limited production is 1979.

12.4.3 General Motors

General Motors has conducted tests on a prechamber variation similar to that tested at the University of Wisconsin by H. K. Newhall, et al. The General Motors engine is in a very early state of development (Ref. 12-2).

12.4.4 Chrysler

In late 1970, Chrysler entered into an agreement with Texaco to evaluate Texaco's stratified charge engine (Ref. 12-7). Chrysler is adding HC/CO catalysts and EGR to two Texaco engines which will be installed in Cricket vehicles for testing. Chrysler is also designing a V-8 stratified charge engine for a normal-size passenger car.

12.5 RANKINE ENGINE

In the Rankine engine system, combustion takes place in an external burner, and heat is then added to the working fluid in a boiler. The external burner can operate at lean air/fuel ratio if desired and, similar to the gas turbine, has potential for low emissions without aftertreatment of the exhaust.

12.5.1 Ford

Ford entered into an agreement in 1970 with Thermo-Electron Company for a joint development program on Rankine cycle engines for automotive use (Ref. 12-1). As part of this effort, emissions have been measured from a full-size burner and simulated boiler operated on a simulated CVS-CH test. The results obtained were (in grams per mile):

HC	CO	NO_x
0.13	0.19	0.26

These emissions are based on the projected flow rates required by the engine to operate over the Federal driving cycle.

Many problems remain to be overcome, however, before this concept could possibly be introduced into production. These problems include condenser size, safety aspects, cost, controls, and engine cooling.

Ford's assessment is that unless technological breakthroughs are made, the engine is too complex and costly for widespread automotive application.

12.5.2 General Motors

General Motors has built and tested steam cars and is continuing work in the field (Ref. 12-2). It also concludes that a technological breakthrough is necessary for this type of engine to become attractive for use in passenger cars.

12.5.3 Chrysler

Past studies by Chrysler have led to a negative view toward the Rankine type of power plant for automotive use for the same types of reasons discussed above (Ref. 12-7), However, recent developments have encouraged Chrysler to reassess its position. It has entered into an agreement with Steam Engine Systems, Inc., to install a Rankine engine in a production vehicle. This is a long-term program, however, and production, if it were to occur, would be many years away.

12.6 STIRLING ENGINE

The Stirling engine cycle which is based on the alternate heating and cooling of an entrapped gas volume is a very efficient cycle. Its combustor is an external combustor and hence has the same potential for low emissions as exists for the Rankine cycle engine. Further emission reduction might be possible by means of a trade-off between fuel economy and emissions.

12.6.1 Ford

In August 1971 Ford entered into a technical exchange agreement with Philips of Holland who has been the most important developer of Stirling engines. Philips' calculations, based on tests with small engines, indicate this type of engine has the potential for meeting 1976 standards (Ref. 12-1).

Recently completed packaging studies by Ford indicate the major problem is large radiator size. Other unresolved problem areas are safety (hydrogen working fluid), cost, and complexity.

Earliest possible production date is estimated to be 1980.

12.6.2 General Motors

General Motors has designed and built a Stirling engine car (Ref. 12-2). The HC and CO emissions were low, but NO_x emissions were high. General Motors believes this engine is too heavy, complex, and expensive for automotive use.

REFERENCES

12-1 Ford Motor Company, "Application for Suspension of 1975 Motor Vehicle Exhaust Emissions Standards," Volumes I and II, 5 April 1972.

12-2 General Motors Corporation, "Request for Suspension of 1975 Federal Emissions Standards," Volumes I and II, 3 April 1972.

12-3 Daimler-Benz, "Statement of Daimler-Benz AG before the Environmental Protection Agency, Washington, D. C.," April 1972.

12-4 Toyo Kogyo Company, Ltd., Transcript of Proceedings -- Auto Emissions Extension -- Environmental Protection Agency, Washington, D. C., 21 April 1972.

12-5 Toyo Kogyo Company, Ltd., "Statement of Toyo Kogyo Company, Ltd.," April 1972.

12-6 Mercedes-Benz Company (Daimler-Benz AG), Transcript of Proceedings -- Auto Emissions Extension -- Environmental Protection Agency, Washington, D. C., 19 April 1972.

12-7 Chrysler Corporation, "Application for Suspension of 1975 Motor Vehicle Emission Standards Pursuant to Section 202(b)(5) of the Clean Air Act," March 1972.

APPENDIX: NONAUTOMOTIVE INDUSTRY TESTIMONY

This appendix is made up of the highlights of the statements made at the EPA Suspension Request Hearings held on April 10-28, 1972 in Washington, D.C., by witnesses that are not part of the automobile industry.

Mr. Rudich

Mr. David A. Rudich is the President of Enviro Plan, a consulting engineering firm involved in a broad spectrum of environmental quality and natural resource management activities which also include automotive emission control. His testimony was specifically directed at technology development within the field of internal combustion engines. These are the significant points in his testimony:

a. The "proper" approach to the control of emissions is by cleaning up the combustion process; not by cleaning up the products from combustion.

b. Enviro Plan has a theoretical design which has promise to meet the 1975-76 requirements and can be applied to current internal combustion engines.

c. Enviro Plan does not have the financial resources to pursue the hardware development and has been unable to stimulate any interest from the automobile industry.

Ms. Leavitt

Ms. Helen Leavitt, author, contends that the automobile is technologically outmoded and should be replaced by public transportation systems. Her position is that the denial of the suspension requests will bring about the recognition of the automobile limitations and result in an earlier diversification of interest by the automobile manufacturers. She envisions that this diversification would include the development of public transportation systems.

Mr. Pancoe

Mr. Arthur Pancoe is the director of the Society Against Violence to Environment (SAVE) and Citizens Action Program in Chicago (CAP). His basic points are (1) do what can be done now, (2) cost of emission controls and replacements should not be a consideration, and (3) people have the right to clean air.

Based on his judgment of the available technology, he recommends that the requirements be reduced to 85 percent of the 1975 standards.

Ms. Reid

Ms. Barbara Reid, Washington representative of Environmental Policy Center, attacks most of the issues involved with quotations from the hearings and reference data which support the denial of the suspension request. Her major concern, which was discussed in much length during the panel questioning, was the averaging concept in the acceptance of production line vehicles. She contends that it should not be allowed on the basis that it is not consistent with the intent of the Clean Air Act and does not serve the interest of the automobile purchaser.

Mr. Clapper

Mr. Louis S. Clapper, Director of Conservation for the National Wildlife Federation, contends that the suspension cannot be considered as "essential to the public interest or the public health and welfare of the United States." He did not address the other issues which bear on this determination. He recommends that people buy less powerful cars. This is based on his opinion that smaller cars produce less emissions.

Mr. Chou

Mr. Hsiao Ta Chou, mechanical engineer, states that the solution to the automobile engine emissions lies in achieving complete combustion in the engine by precise control of the air/fuel mixture and that he has developed a technology for the determination of the instantaneous value of the true fuel mass flow rate for controlling the exact mixture under all conditions. His complaint is that while he has the solution, he cannot interest anyone in using his technology.

David G. Hawkins

Mr. Hawkins is an attorney with the National Resources Defense Council. It was Mr. Hawkins' opinion that:

a. There has been no demonstration that a suspension is essential to the public interest.

b. None of the applicants has established that he has made all good faith efforts to comply with the standards.

c. It has not been established that the technology is not available to meet the standards.

Accordingly, Mr. Hawkins offered the following proposal to EPA. Concurrent with the denial of the requests, the Administrator should request from Congress an emission tax on automobiles which do not meet the 1975 standards. The tax would be applicable to the cars of any manufacturer who in the future requested and was granted a suspension of the standards. The amount of the tax would be keyed to the level of the interim standards set at the time of suspension. The higher the interim standard, the higher the tax. Individual manufacturers would also be permitted to request certification of their vehicles at levels more stringent than the interim standard in return for a proportional tax reduction.

Clarence M. Ditlow

Mr. Ditlow represented the Public Interest Research Group, Washington, D.C. It was his opinion that a one-year suspension is not essential to the public health and welfare of the United States. He stated that the extent and direction of emission control research and development by the motor vehicle manufacturers preclude the finding of any good faith attempt to meet the 1975 vehicle emission standards.

It was Mr. Ditlow's recommendation that the suspension requests be denied and that EPA should recommend that Congress enact legislation setting an interim standard (unspecified) and requiring retrofitting of all pre-1968 light duty motor vehicles with emission control technology sufficient to lower total emissions from all motor vehicles to at least the levels attainable if the 1975 light duty vehicle emission standards were in effect.

J. Wagshal, M. P. Walsh, F. C. Hart, J. L. Rankin, D. Shapiro

This group appeared before the panel on behalf of 4 cities and 21 states in opposition to the granting of any suspension to the 1975 standards. It was their contention that under the law, as defined by the Clean Air Act, the applicants had not demonstrated that it was in the public interest or welfare to grant a suspension, that a good faith effort had not been made, and that it had not been shown that the technology was not available. They also expressed the opinion that the National Academy of Sciences report had become obsolete in view of the progress which had been made since it had been published and in view of the evidence presented at the hearings.

Louis B. Lombardo

Mr. Lombardo is currently forming an organization known as the Public Interest Campaign. It was his opinion that the suspension request should be denied on the basis that (1) it was not in the best interest of the United States to grant a suspension; (2) a good faith effort has not been demonstrated by the auto manufacturers; (3) the applicants have not demonstrated that the technology is not available; and (4) in his opinion, the National Academy of Sciences report indicates that technology is available to meet the standards.

Mr. Lombardo also requested that EPA subpoena manufacturers of fuel injection systems (e.g., American Bosch and Bendix) to obtain further information on the capabilities of fuel injection systems to meet the 1975 standards.

Robert J. Rauch

Mr. Rauch is assistant Legislative Director of Friends of the Earth. The initial portion of his testimony dealt with a discussion of the credibility of the auto manufacturers' claim that the converters they have tested cannot come close to meeting the 50,000 mile standard whereas the converter manufacturers have testified that the standards can be met. It was Mr. Rauch's opinion that the catalyst manufacturers stand to lose more than the auto manufacturers if the catalytic converters do not meet the 1975 standards, and that the testimony of the catalyst manufacturers is, therefore, more credible.

Mr. Rauch also discussed the legal and moral pros and cons of granting the extension and, in conclusion, recommended that the request for suspension be denied since, in his opinion, the testimony of the catalyst manufacturers alone casts sufficient doubt that meeting the 1975 standards is technologically infeasible.

I. Walton Bader

Mr. Bader is a trustee of the Heart Disease Research Foundation which is engaged in research activities directed toward the reduction of heart and lung ailments.

Mr. Bader's testimony consisted primarily of the following statement. The Heart Disease Research Foundation has determined that a correlation exists between the increase of heart and respiratory ailments and the increase of pollution in the metropolitan areas. The Foundation's position is that the automobile is the primary cause of pollution in most metropolitan areas. Therefore, it opposes the request by the automobile manufacturers for a one-year extension to the 1975 standards.

William D. Balgord

Mr. Balgord represented the New York State Department of Environmental Conservation. This organization, in cooperation with the New York City Department of Air Resources, has completed two years of a three-year research effort to develop catalytic emission control systems independent of the auto manufactureres. Its objective is to demonstrate the technical and economic feasibility of these systems in relation to the 1975 standards. The effort has been focused on reducing NO_x, with no effort being made to develop HC/CO oxidizing catalysts. Testing to date has been conducted on a bench-mounted V-8 engine operated over a simulated durability driving cycle. Commercially available unleaded fuel has been used for all tests.

The most promising NO_x reducing catalysts appear to be a base-metal catalyst mounted on a honeycomb substrate. Preliminary results indicate a potential for greater than 99 percent reduction of NO_x in a two-catalyst converter system which also controls HC and CO (no details were presented of the oxidizing catalyst).

J. Howard Flint

Mr. Flint is counsel for the Pancoastal-PXP Corporation, Hartford, Connecticut. Mr. Flint presented brief verbal testimony together with written and film documentation regarding the Corporation's findings on the Pritchard steam-driven automobile being developed in Australia. No specific details were provided in the verbal testimony other than the general statement that this vehicle, without a catalytic converter, meets the 1975 standards and exceed the 1976 NO_x standard by approximately 0.2 percent. Meeting the 1976 NO_x requirement does not present any problem to the Pritchard Co., according to Mr. Flint.

Department of Air Resources, New York City

Testimony on behalf of the New York City Department of Air Resources was presented by Mr. Fred C. Hart, Commissioner, Department of Air Resources; Mr. Michael P. Walsh, Director, Bureau of Motor Vehicle Pollution Control; and Mr. Jerome Wagshal, Special Counsel to the City of New York. The primary purpose of their testimony was to report the results to date of a program to evaluate the potential of an Engelhard PTX-5 catalytic converter as a retrofit device for light duty vehicles in urban service.

The test fleet used in this program consisted of six police cars, four assigned as patrol vehicles and two as inspector vehicles. One of the patrol vehicles was not equipped with the retrofit devices and served as the baseline control vehicle. All vehicles were 1971 6-cylinder, 225-CID Plymouth Furys with automatic transmission.

Five of the vehicles were equipped with an Engelhard PTX-5 noble metal catalyst and secondary air injection between the exhaust manifold and the catalytic converter. No NO_x control was attempted nor was an overtemperature protection system used. All six test vehicles were equipped with electronic ignition systems.

The fuel used was commercially available Amoco Super Premium gasoline with a Research Octane No. of 100.3. A random sampling of the amount of lead in the fuel showed, for the most part, 0.01 gm/gal or less although one sample was found to contain approximately 0.1 gm/gal while another was 1.0 gm/gal. This "contamination" was believed to be the expected variation that might be encountered with the normal distribution of various grades of fuel. No attempt was made to correlate the lead content of the fuel with any observed deterioration in the catalyst efficiencies.

All vehicles were tuned to the manufacturer's recommended specifications at the start of the test. Subsequent maintenance was performed according to standard Police Department procedures and consisted of an oil change and new oil filter every 4,000 miles. Spark plugs were checked every 6,000 miles and replaced as necessary.

The driving pattern experienced by the four patrol vehicles (including the control vehicle) was described as a combination of extensive periods at idle as well as substantial amounts of high-speed driving. These cars were in 24-hour per day operation and accumulated 3500-4500 miles per month. The inspector vehicles experienced what was described as reasonably normal driving and accumulated mileage at the rate of 1,000-1,500 miles per month.

No overheating of the catalytic converters was experienced and although specific data were not obtained, no overt evidence of an increase in fuel consumption or any decrease in performance was observed.

All emission tests were performed in accordance with the 1972 CVS test procedure approximately every 4,000 miles. Emission results are shown in Table A-1. Although these vehicles do not meet the 1975 standards, a significant reduction in the HC/CO emission levels was achieved with what seems to be a comparatively unsophisticated emission control system.

An additional program is being initiated using Engelhard, UOP, and Oxy-Catalyst to retrofit a small fleet of heavy duty sanitation trucks. It is planned to have 15 vehicles converted by May 1972.

Based upon the results achieved from the retrofit program, it was concluded by Mr. Walsh that it should be possible to meet the 1975 standards by controlling the catalyst temperature, the choke mechanism, and the amount of oxygen injected into the converter.

Richard S. Morse

Mr. Morse is a senior Professor at the Sloan School of Management, Massachusetts Institute of Technology. He also is Chairman of the Board of the Steam Engine Systems Corporation which has a contract with EPA to build a steam automobile power plant. The emissions from the burner of this power plant were reported to be 0.09 gm/mi HC, 0.60 gm/mi CO, and 0.16 gm/mi NO_x. The test procedure under which these results were obtained was not specified.

It was Mr. Morse's opinion that short of a wartime-type crash program, it would be very difficult to mass produce a steam powered vehicle by 1975 and would probably take three years even on a crash basis.

Table A-1. New York City Light-Duty Vehicle Retrofit Program

Veh. No.	Date	Actual Miles	Catalyst Miles	Meter Hours	Catalyst Hours	Emissions, gm/mi[a]		
						CO	HC	NO_x
378	10/15/71	3,899	Before	98	Before	54.8	5.36	--
	12/14/71	6,026	1,028	199.7	47.7	12.9	0.86	6.19
	01/02/72	7,292	2,294	256.2	112.2	14.0	1.10	7.39
	03/08/72	12,357	7,359	555.1	403.1	17.8	1.17	7.77
Conversion: 4,998 mi - 152 hr								
476	10/15/71	3,119	Before	67	Before	76.3	7.47	--
	11/18/71	4,457	7	143.5	0.5	9.2	0.95	2.40
	12/16/71	4,952	502	168	25	3.3	0.56	5.34
	01/13/72	6,058	1,608	223.1	80.1	3.6	0.57	5.62
	03/09/72	7,632	3,182	302.1	159.1	5.0	0.45	5.52
Conversion: 4,450 mi - 143 hr								
1123	10/08/71	6,552	--	--	--	51.3	6.49	--
	12/10/71	14,460	--	--	--	41.0	2.41	3.82
	01/19/72	18,892	--	--	--	45.2	2.20	5.99
	02/17/72	20,815	--	--	--	48.8	2.38	4.37
	03/23/72	23,831	--	--	--	50.7	5.01	3.67
Control								
1693	10/07/71	15,860	Before	705	Before	47.5	4.55	--
	10/12/71	15,892	0	708.2	0	20.1	1.61	--
	10/14/71	15,902	10	718.2	1	13.7	1.86	--
	11/24/71	21,147	5,255	1205	496.8	15.2	0.94	6.87
	12/08/71	23,110	7,218	1396	687.8	20.6	0.88	--
	01/20/72	28,561	12,669	1904.9	1196.7	12.5	0.93	6.94
	02/16/72	32,361	16,750	2294.6	1586.4	14.7	1.08	7.47
	03/24/72	35,834	19,942	2264.4	1956.2	12.0	1.75	3.59
Conversion: 15,892 mi - 708.2 hr								
1866[b]	10/08/71	6,758	Before	704	Before	55.8	5.46	--
	10/14/71	6,836	3	710	0	13.6	1.44	--
	10/29/71	8,456	1,623	909	199	3.0	0.47	--
	11/24/71	12,352	5,519	1331	621	6.9	0.83	4.33
	12/22/71	15,234	8,401	1655	945	10.9	1.06	4.78
	01/06/72	17,806	10,973	1944	1234	16.4	1.72	4.97
	02/17/72	22,122	15,289	2630.1	1920.1	17.4	1.61	7.99
Conversion: 6,833 mi - 710 hr								
2351	10/08/71	6,534	Before	487	Before	51.7	5.36	--
	12/09/71	14,979	2,657	1437	225	18.7	1.04	5.07
	01/07/72	18,377	6,055	1820	608	20.4	1.11	8.80
	02/10/72	22,816	10,496	2414.3	1203.3	18.3	1.48	7.05
	03/22/72	29,786	17,464	3208	1996	17.8	2.35	5.03
Conversion: 12,322 mi - 1212 hr								

[a] 1972 Federal test procedure

[b] Add 762.8 hr to all subsequent meter readings

Mr. Morse summarized his testimony by stating that from the point of view of public interest and feasibility, he felt that less stringent standards should be adopted which roughly paralleled the California standards and suggested a NO_x standard of 1.0-1.5 gm/mi. This, in his view, would result in both improved fuel economy and driveability.

Union Oil

The Union Oil Company testimony may be summarized as follows:

a. The automotive emission standards are too severe and should be relaxed.

b. The 50,000-mile durability requirement for the catalyst should be shortened.

c. Exhaust emission controls should be mandatory on all cars on the road.

d. Annual inspection for all cars should be mandatory as a condition of license renewal.